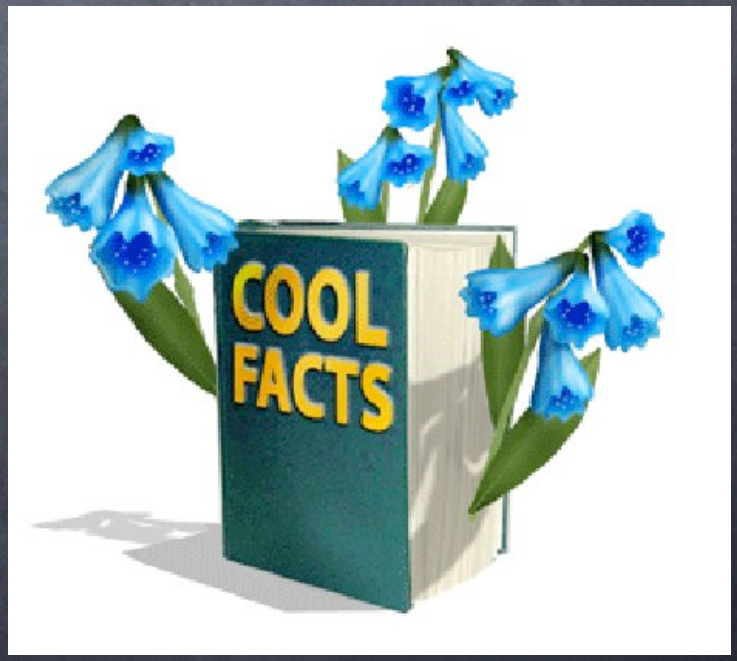
Earthscope Institute on the spectrum of fault slip behaviors

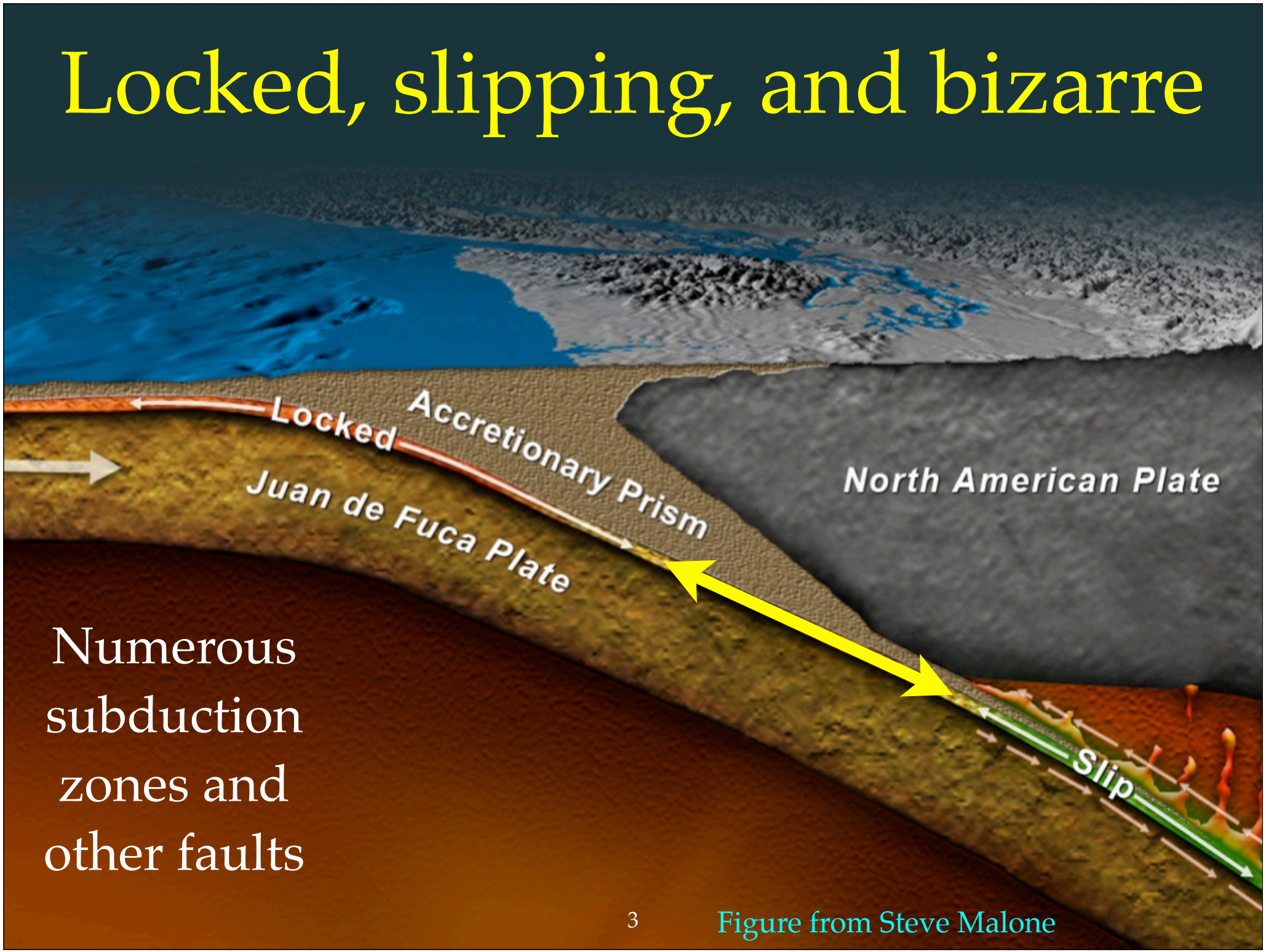
The mystery of fault tremor; where, when, how, and why?

Range of talks

- Review
- Seismic and geodetic observations
- Lab and geological observations
- Theory and models
- The path ahead



Locked, slipping, and bizarre

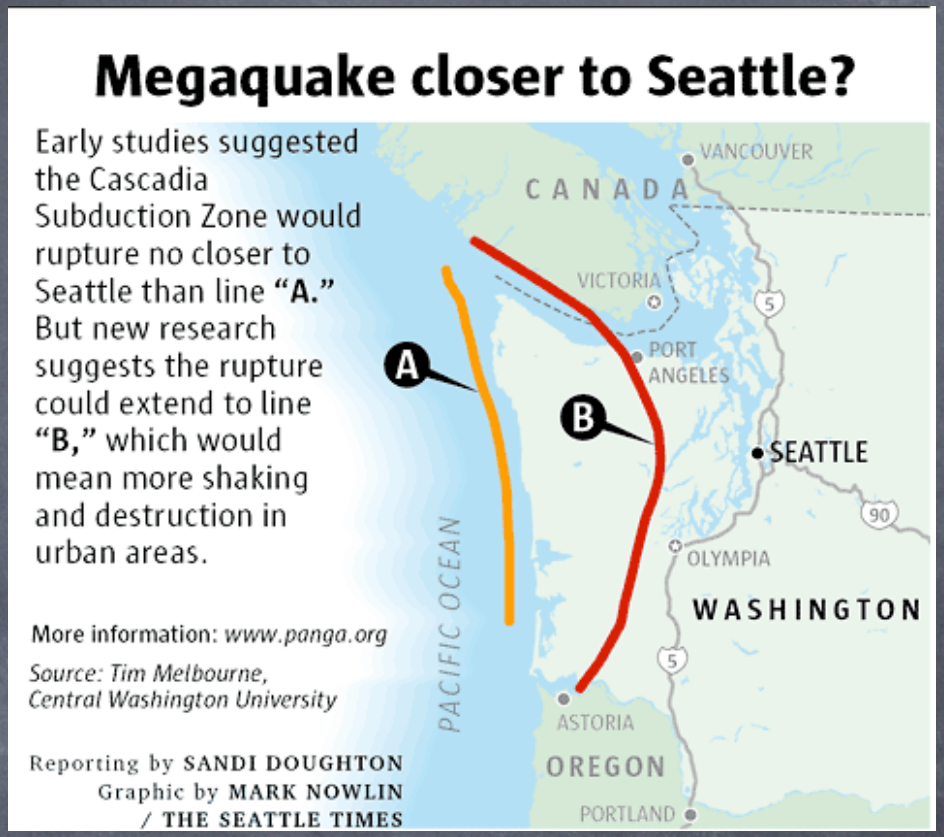


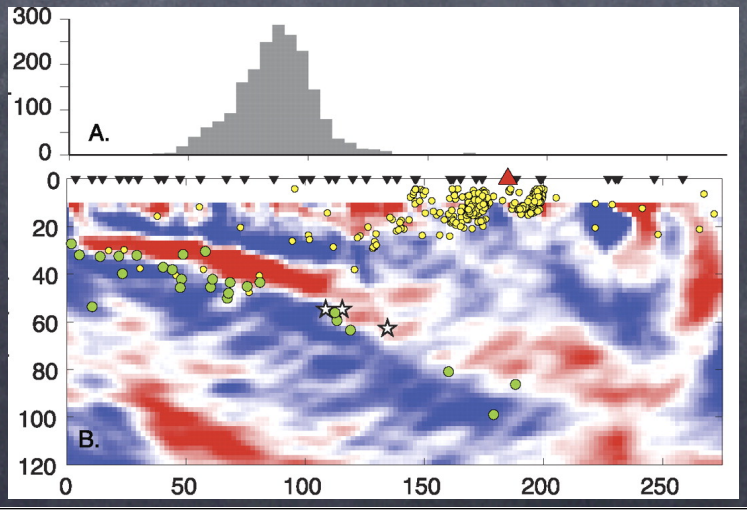
Numerous subduction zones and other faults

Figure from Steve Malone

Several reasons for public to care

- Are locations of intra- and inter-plate quakes illuminated by tremor geometry?
- Crustal earthquakes distribution?
- Does tremor pattern change before megaquakes?

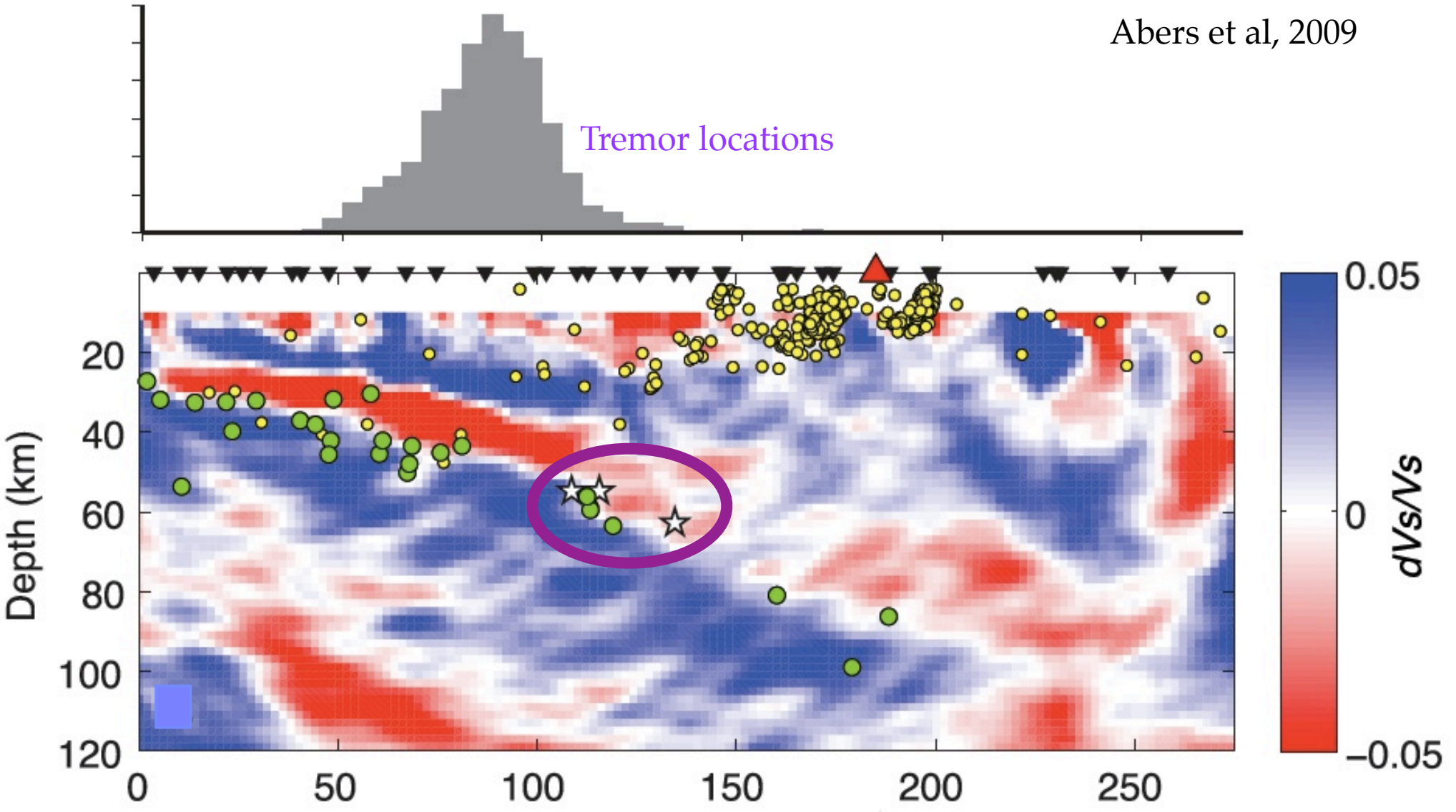




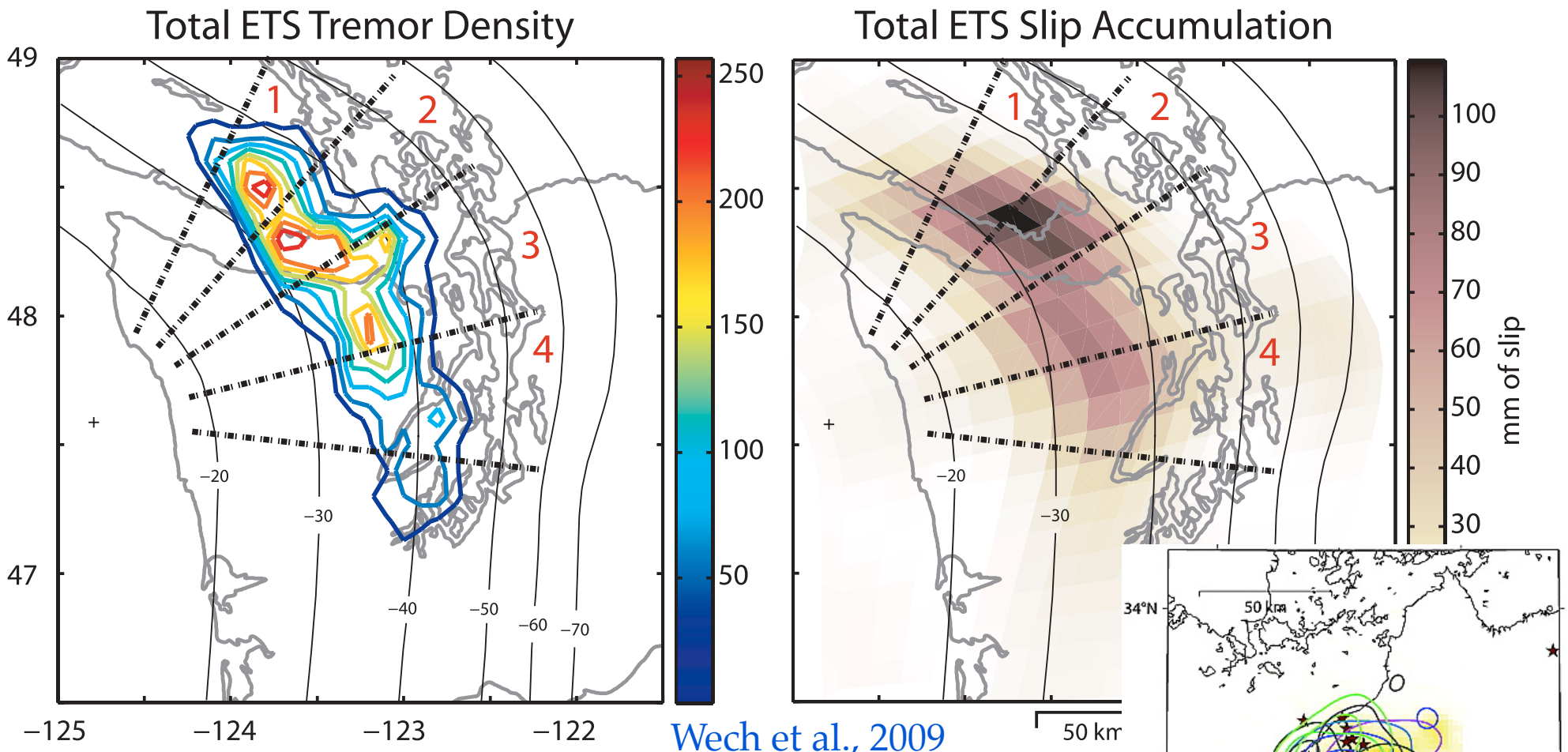
Nov. 17, 2009 in Seattle Times

Abers et al., Geology, 2009

Related to big earthquakes?



Tremor and slow slip coincide in space



Wech et al., 2009

Hirose & Obara, JGR, 2010

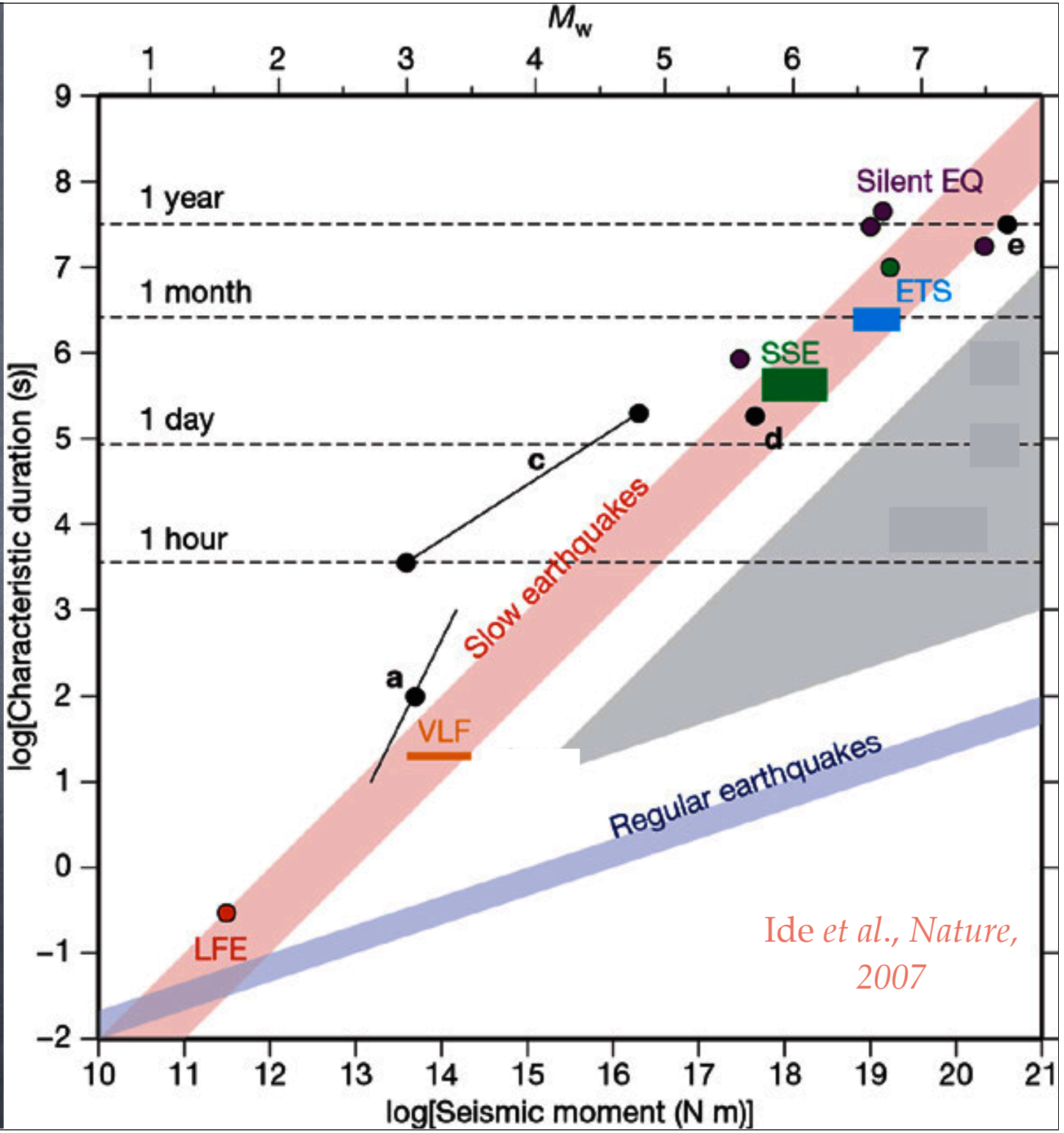
Two kinds of quakes

old

M ~ duration cubed

new

M ~ duration

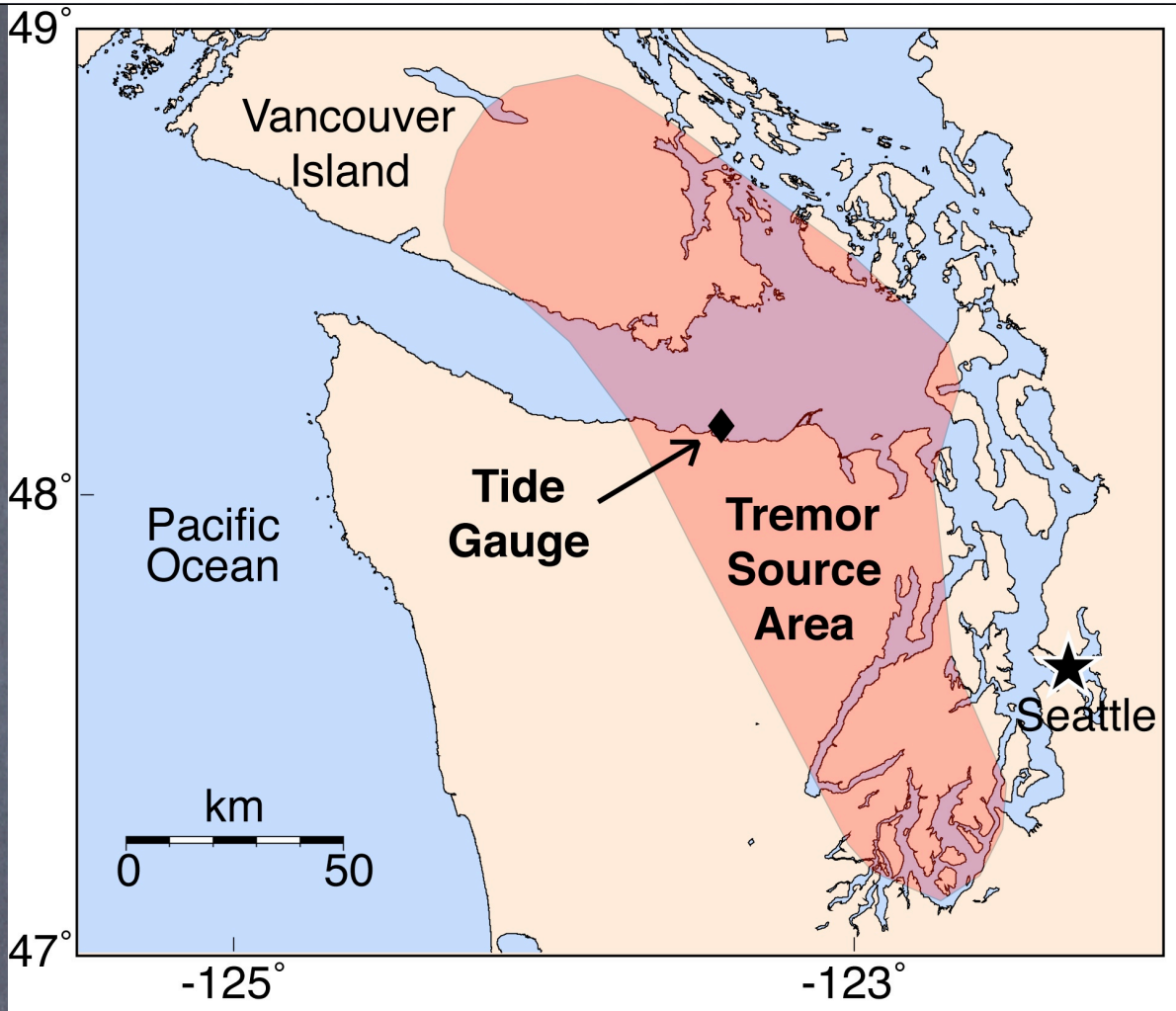


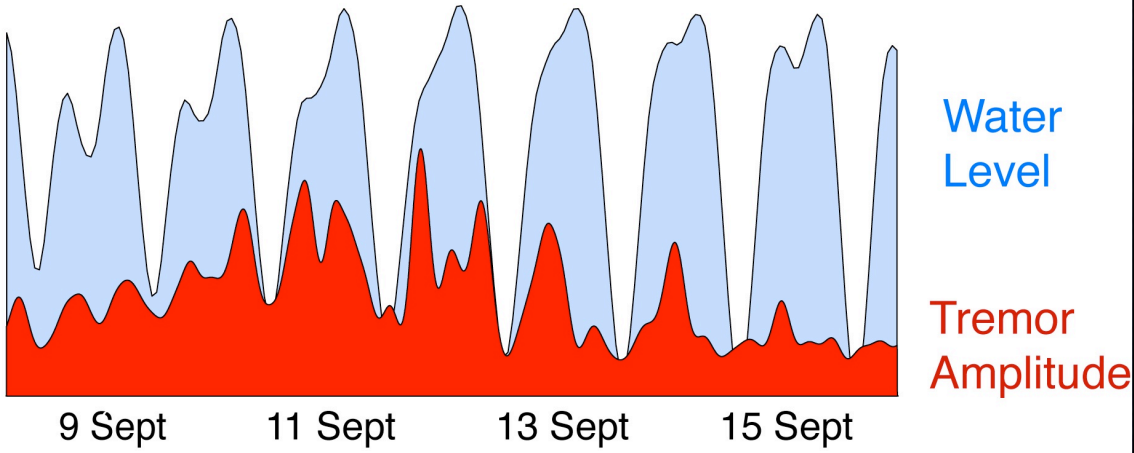
Ide *et al., Nature, 2007*

High water -> More tremor

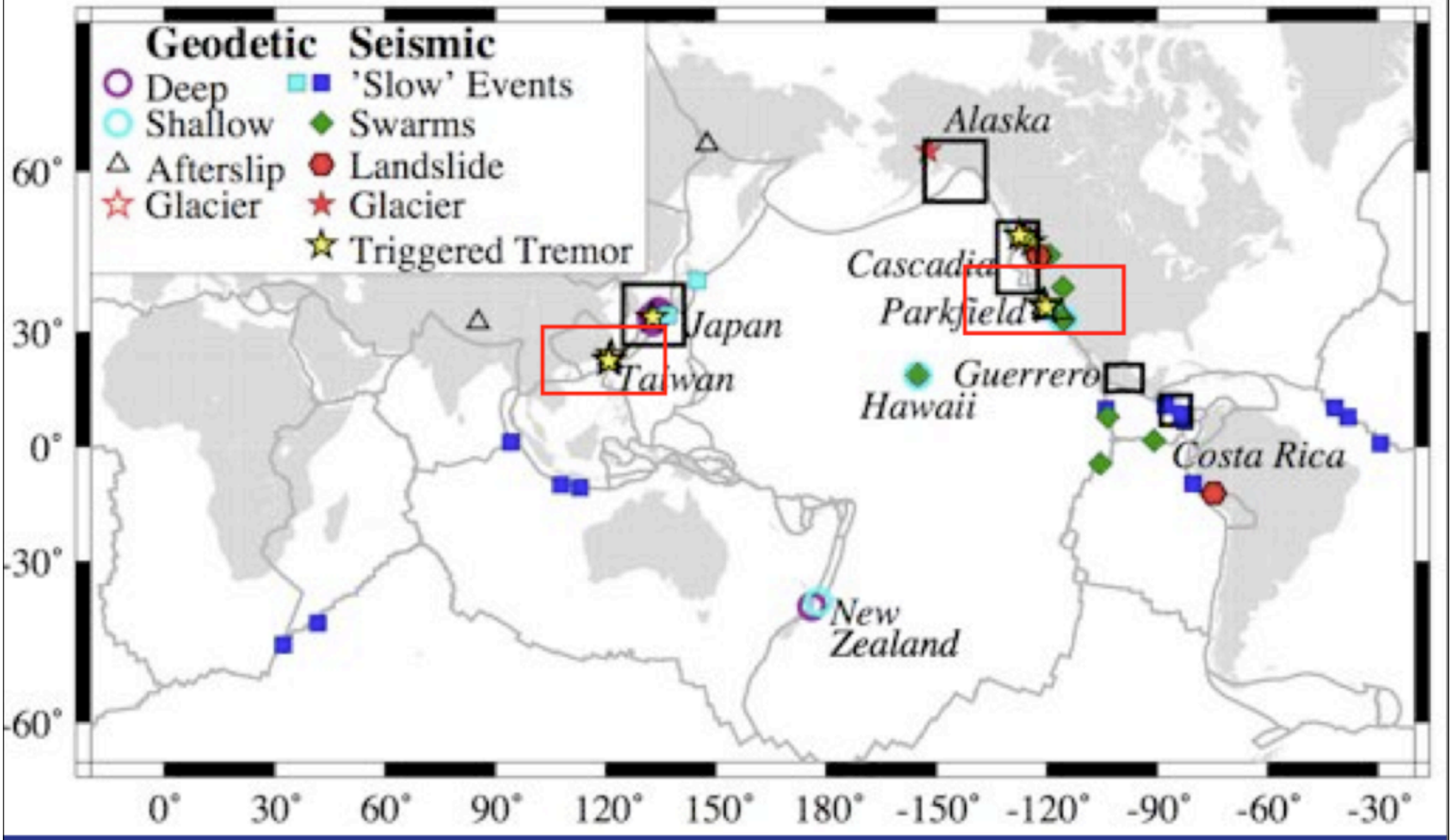
more stress -> more tremor
also seen for Japan, Vancouver Is

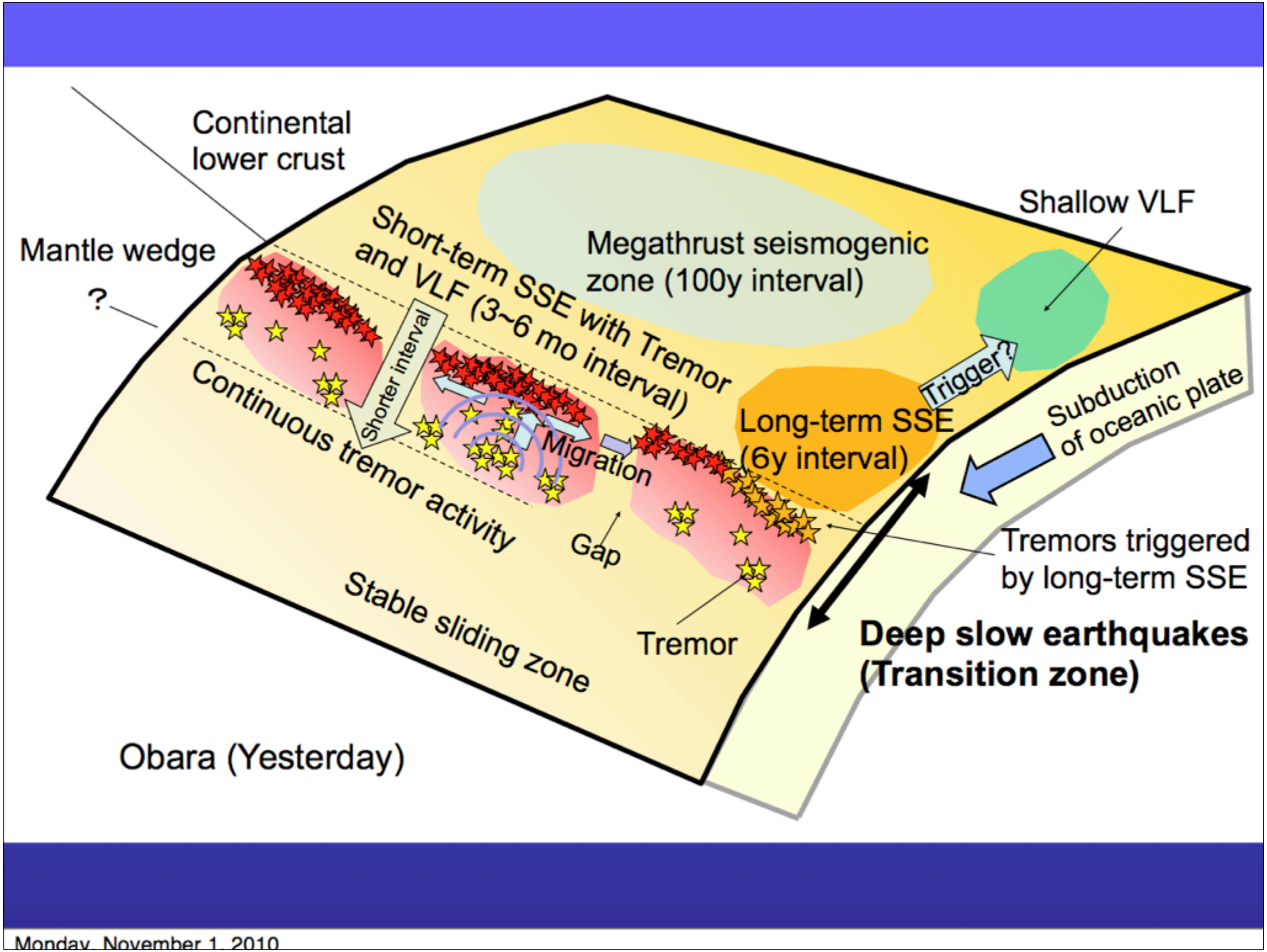
Rubinstein *et al.*, 2007



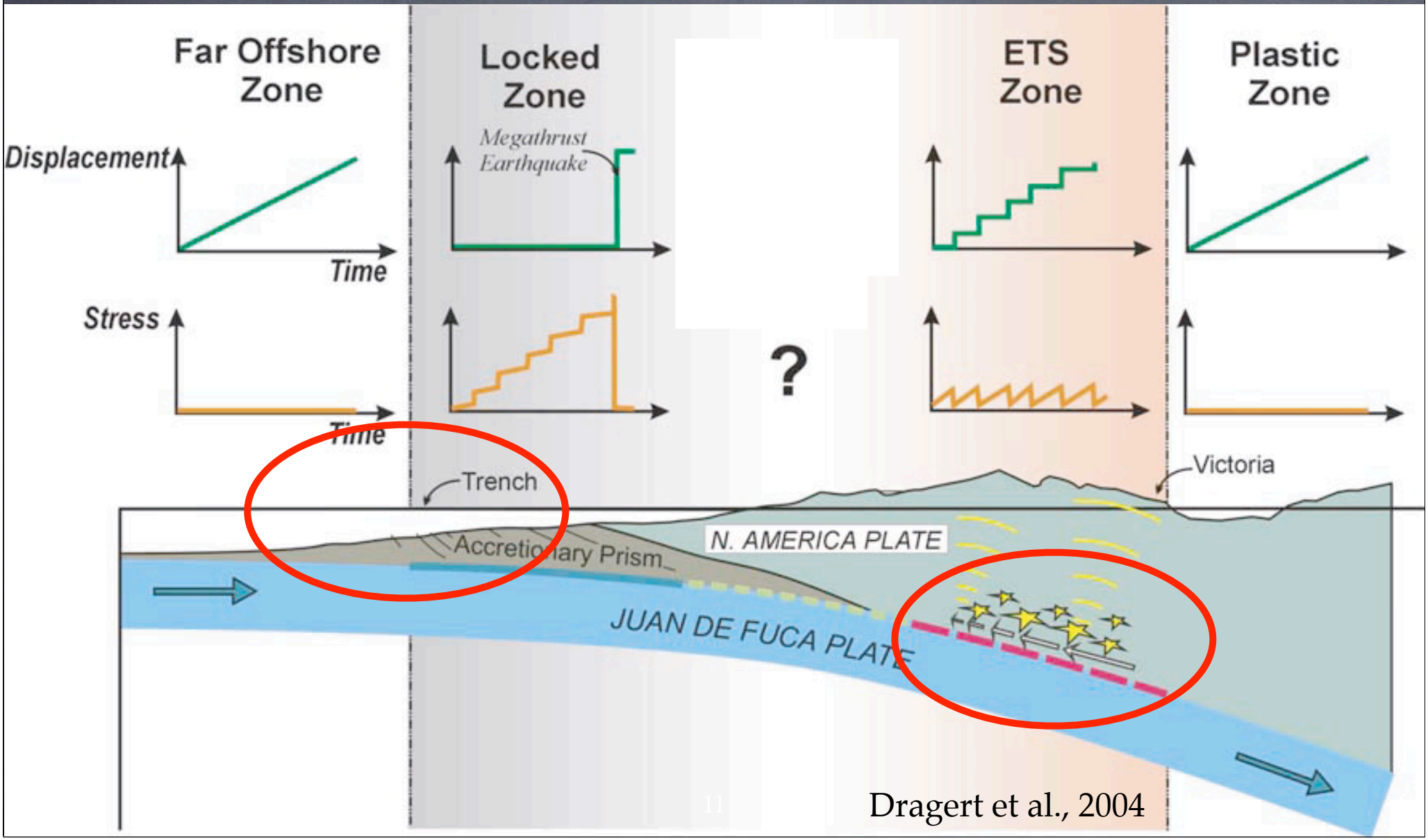


Maps showing where tremor and slow-slip events have been observed (Peng and Gomberg, NGEO, 2010)



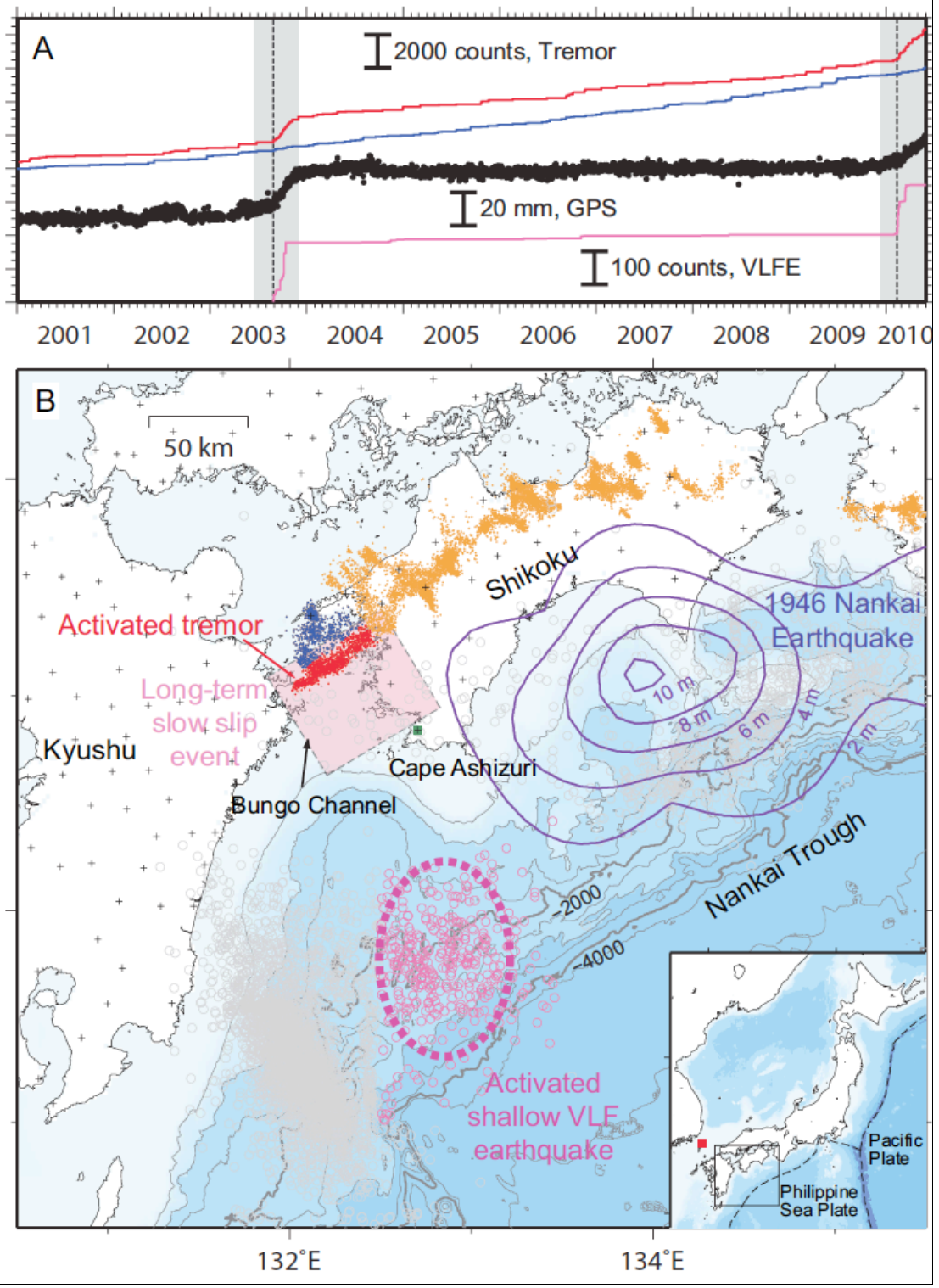

Continental lower crust
Mantle wedge
?
Short-term SSE with Tremor and VLF (3~6 mo interval)
Megathrust seismogenic zone (100y interval)
Shallow VLF
Shorter interval
Migration
Trigger?
Long-term SSE (6y interval)
Subduction of oceanic plate
Continuous tremor activity
Gap
Tremors triggered by long-term SSE
Stable sliding zone
Tremor
Deep slow earthquakes (Transition zone)
Obara (Yesterday)

Episodic Tremor and Slip schematic

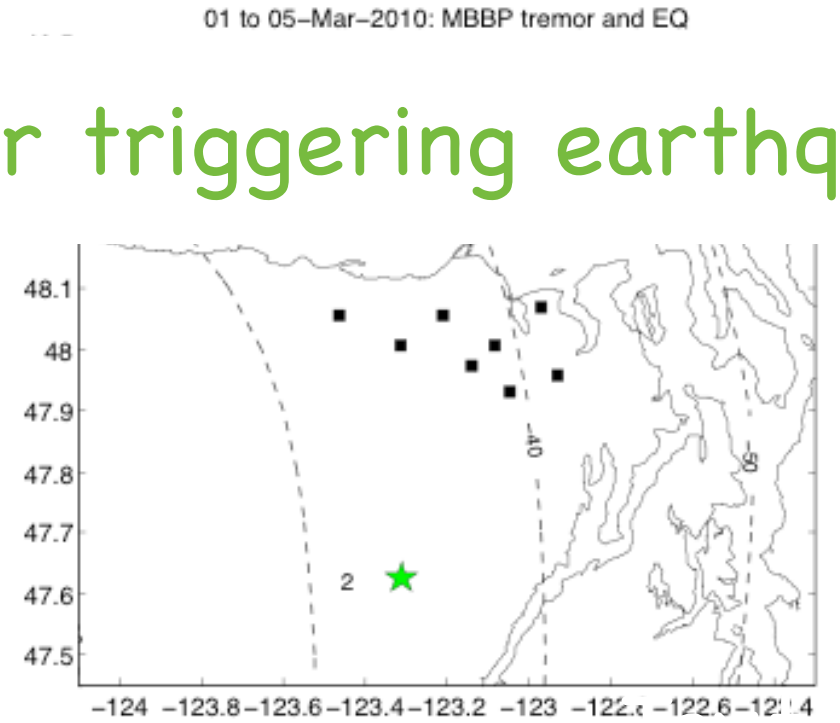


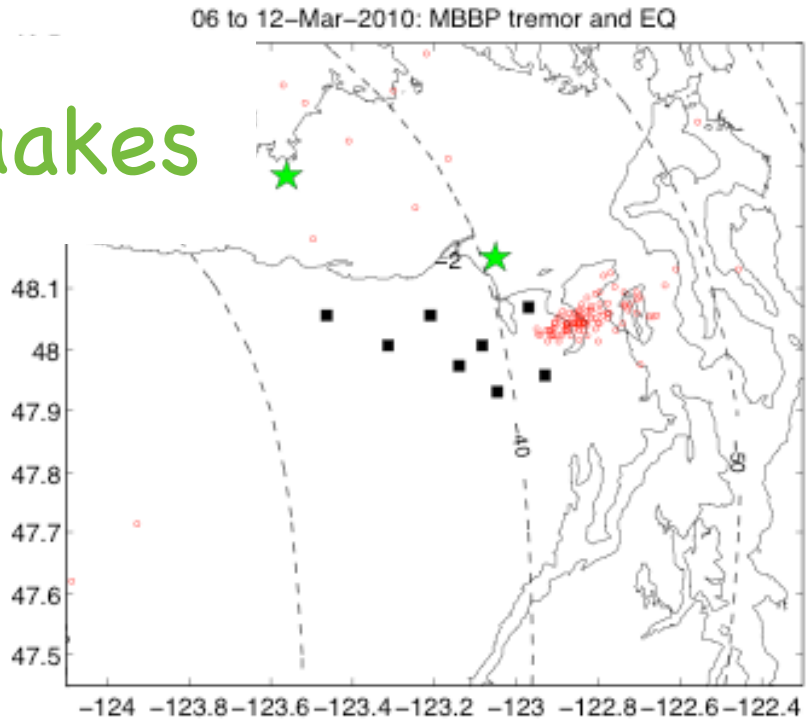
Dragert et al., 2004

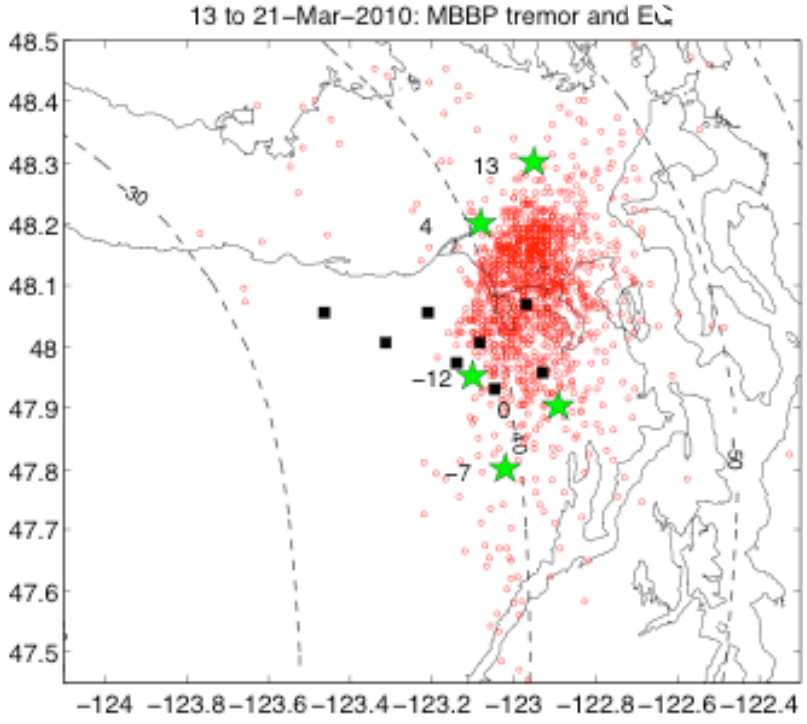
- Long-dip-direction ETS in Japan,
- soon to be published in Science

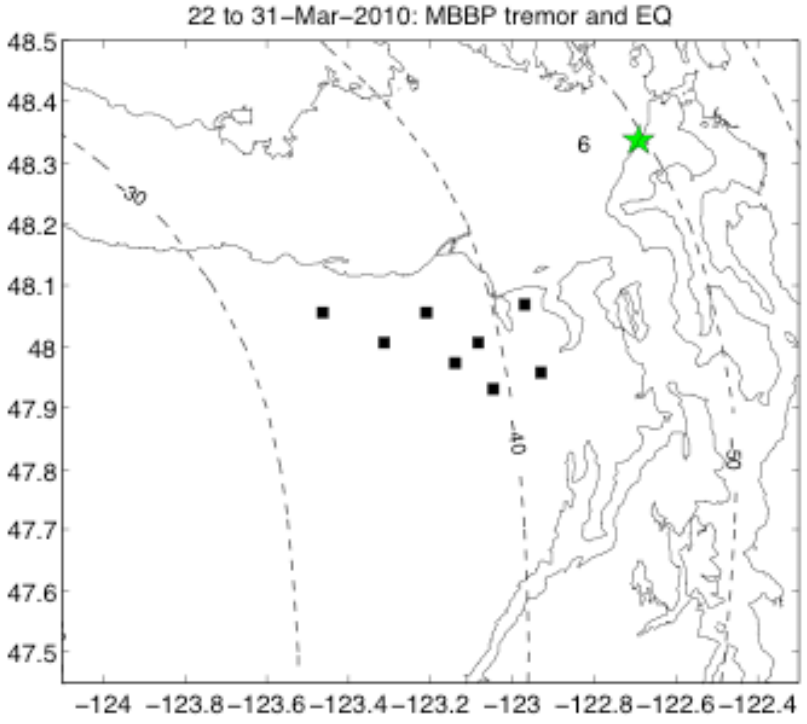


Tremor triggering earthquakes

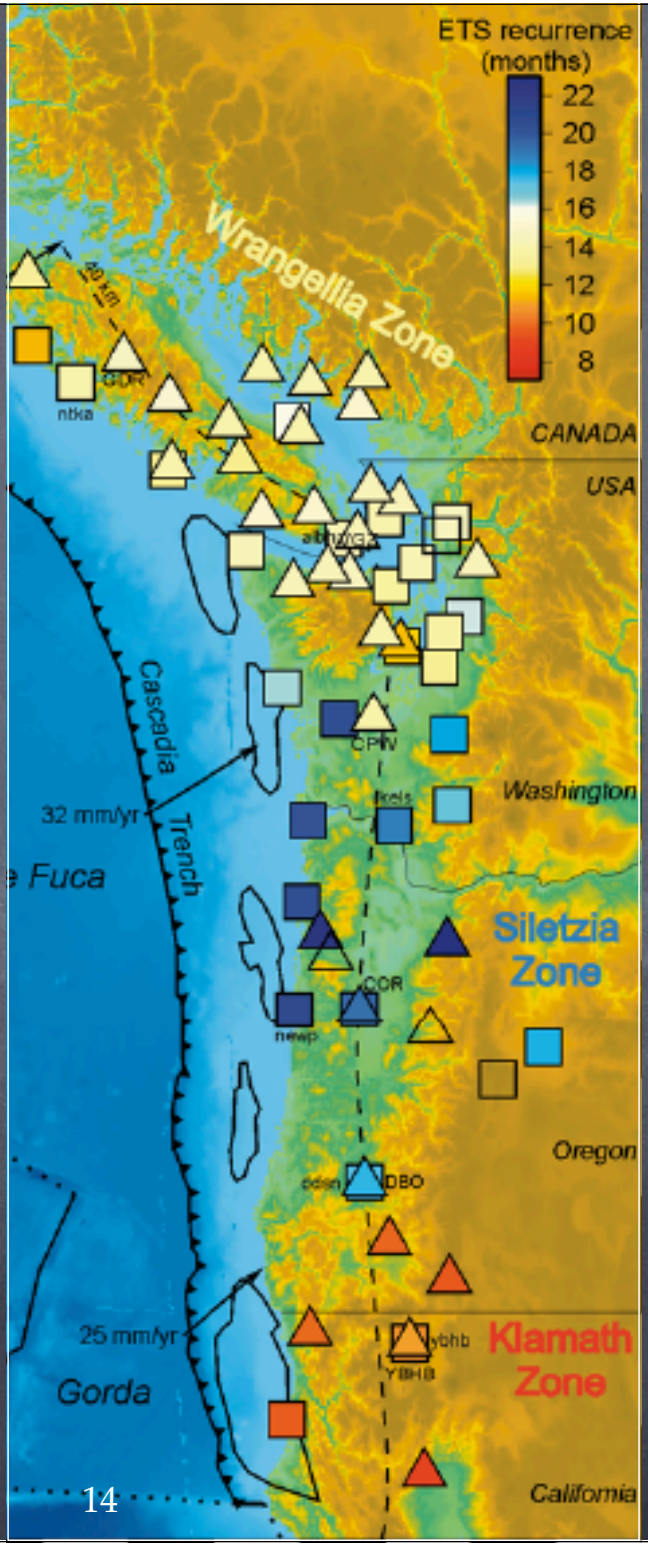








Multiple segments with regular recurrence intervals

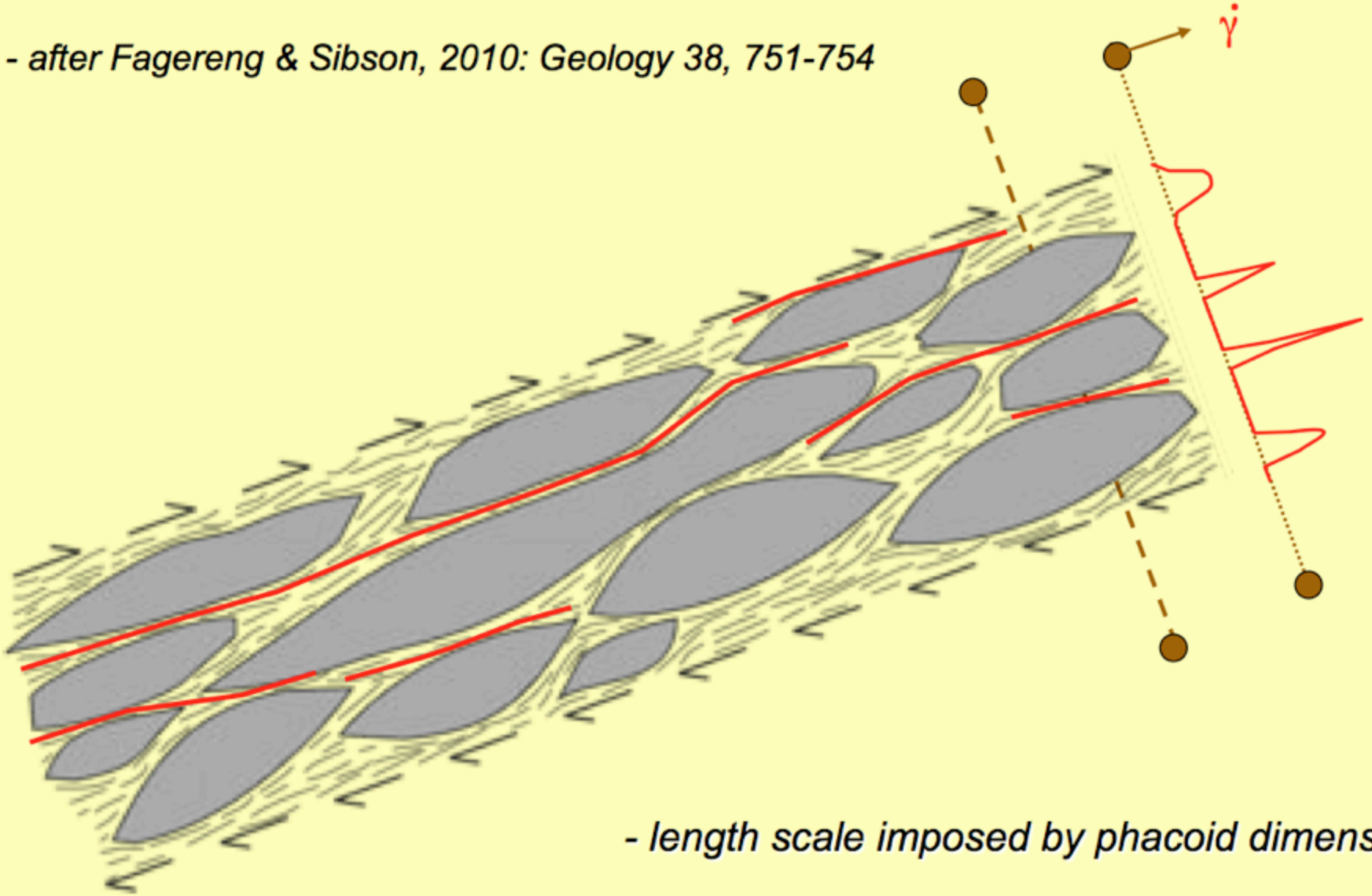


Color is ETS recurrence interval

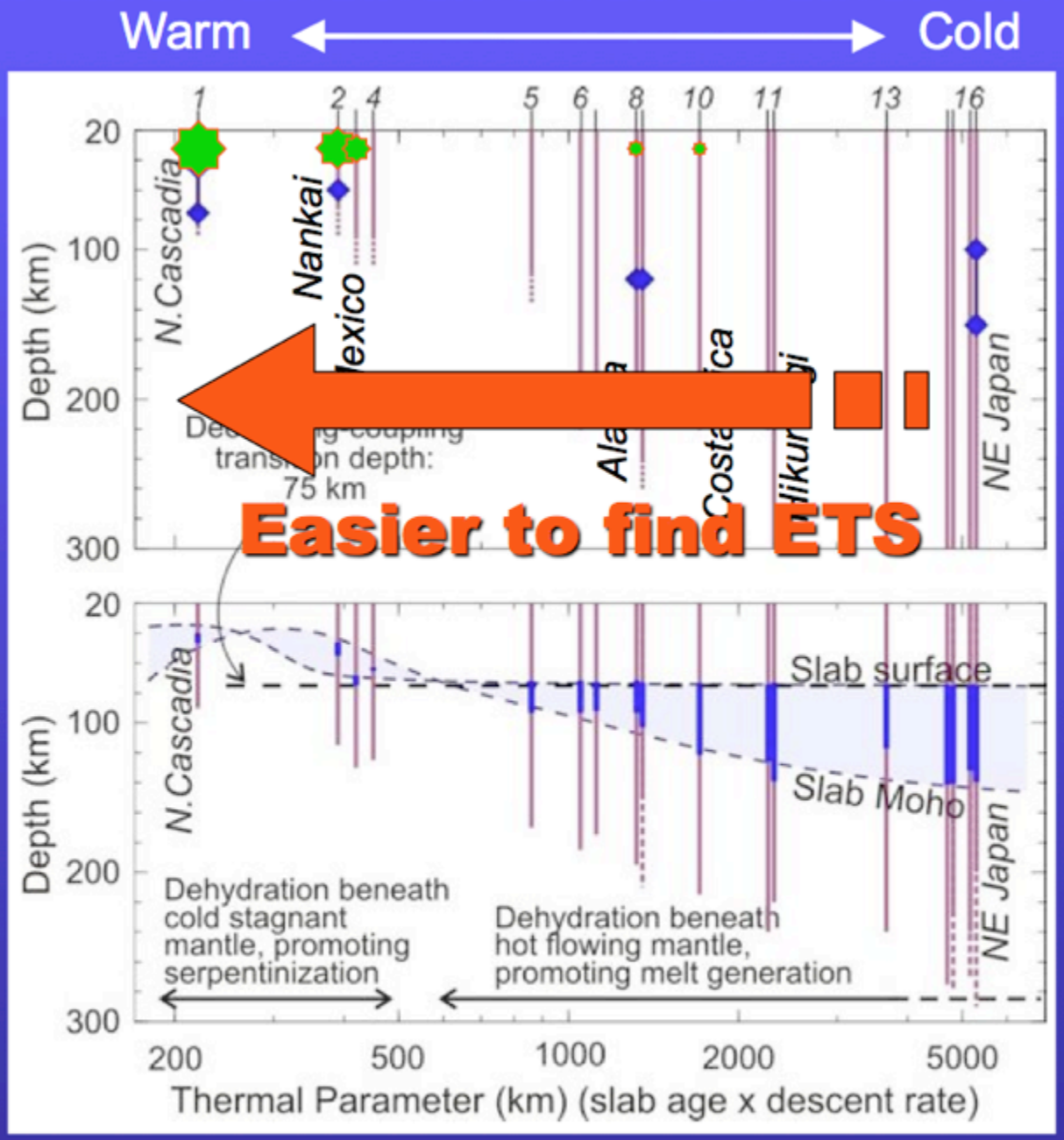
Brudzinski & Allen, 2007

Locally Amplified Shear Strain Rates in Mélange Shear Zones Inducing Distributed Brittle Failure

- after Fagereng & Sibson, 2010: Geology 38, 751-754



- length scale imposed by phacoid dimensions



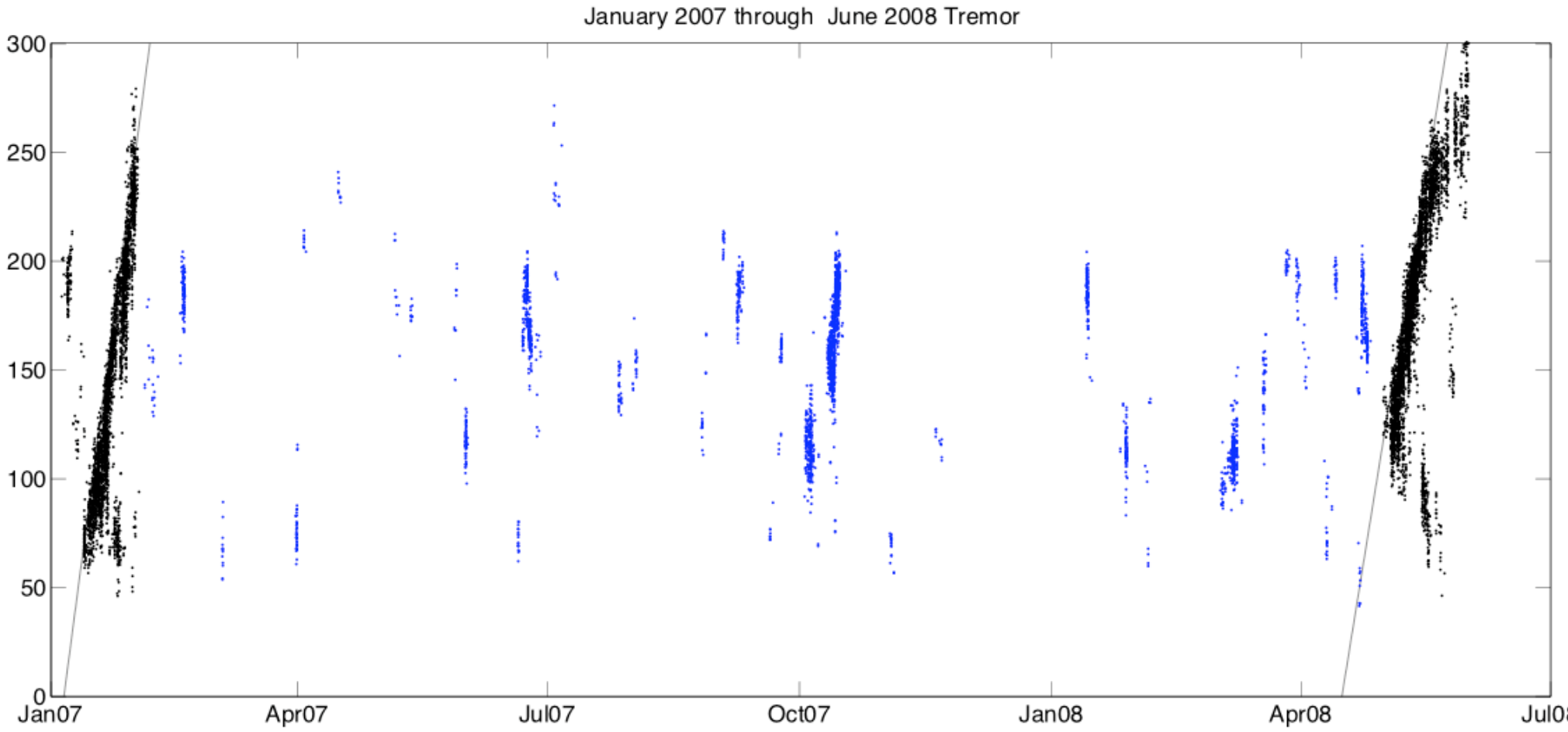
Survival depth of basaltic oceanic crust (blue) and depth range of intraslab earthquakes (purple)

Model-predicted peak dehydration depth (blue) and serpentine stability in subducting slab (purple)

Wada and Wang, 2009

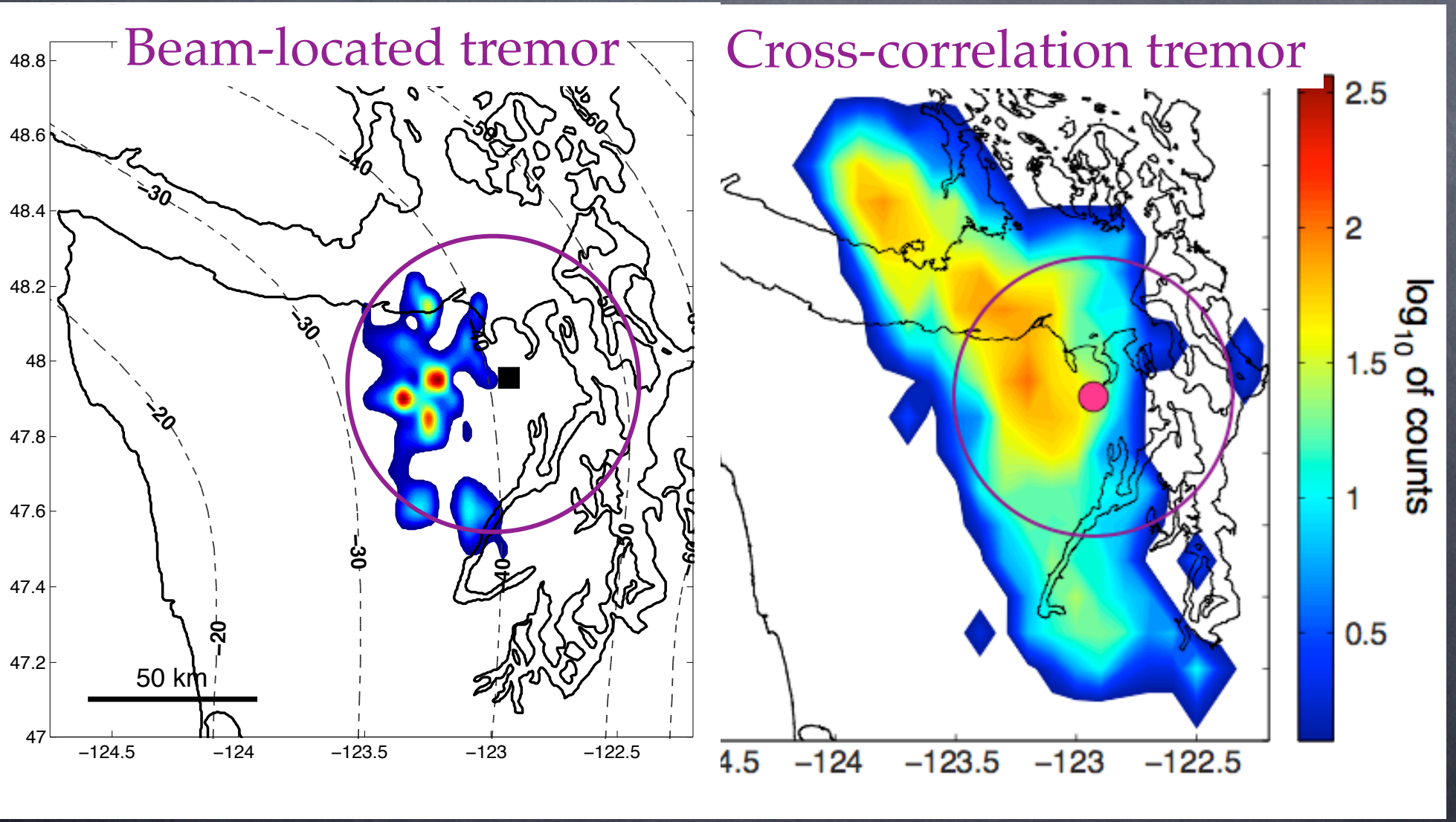
Smaller events between major ETS episodes

between two Cascadia ETS events, projected along strike

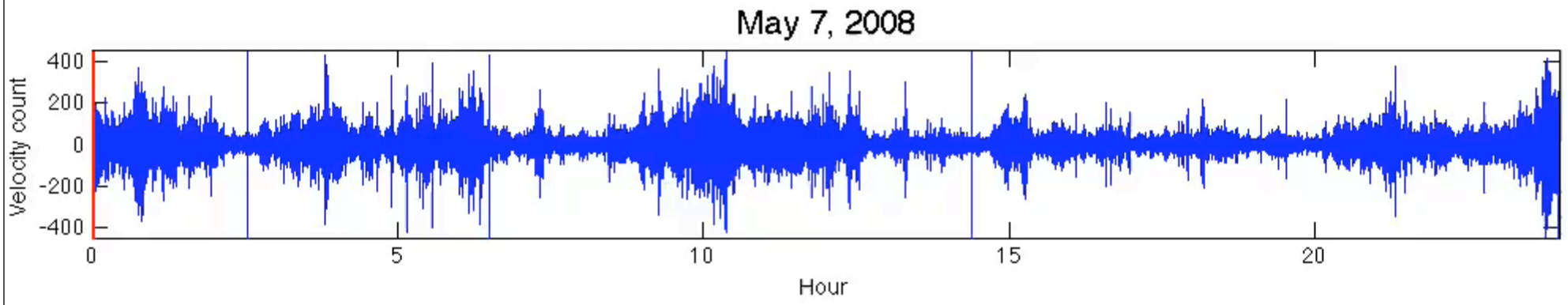


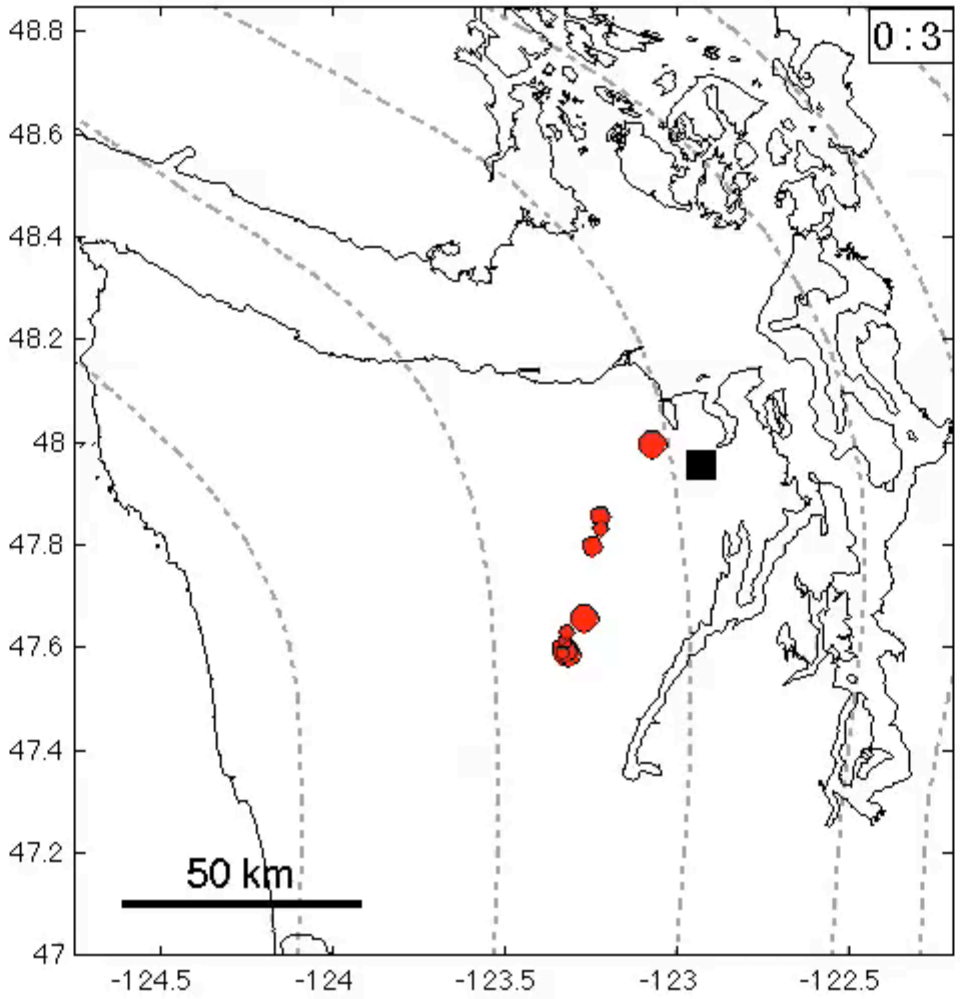
Wech *et al.*, in press, GRL

Tremor more irregular than previously mapped?



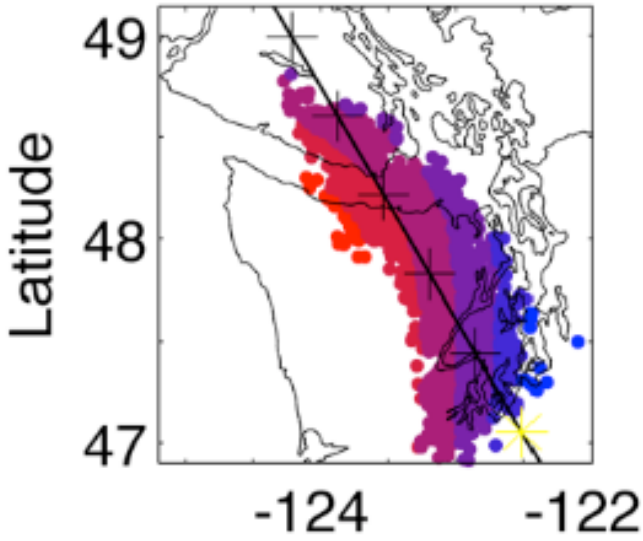
Ghosh et al., 2009

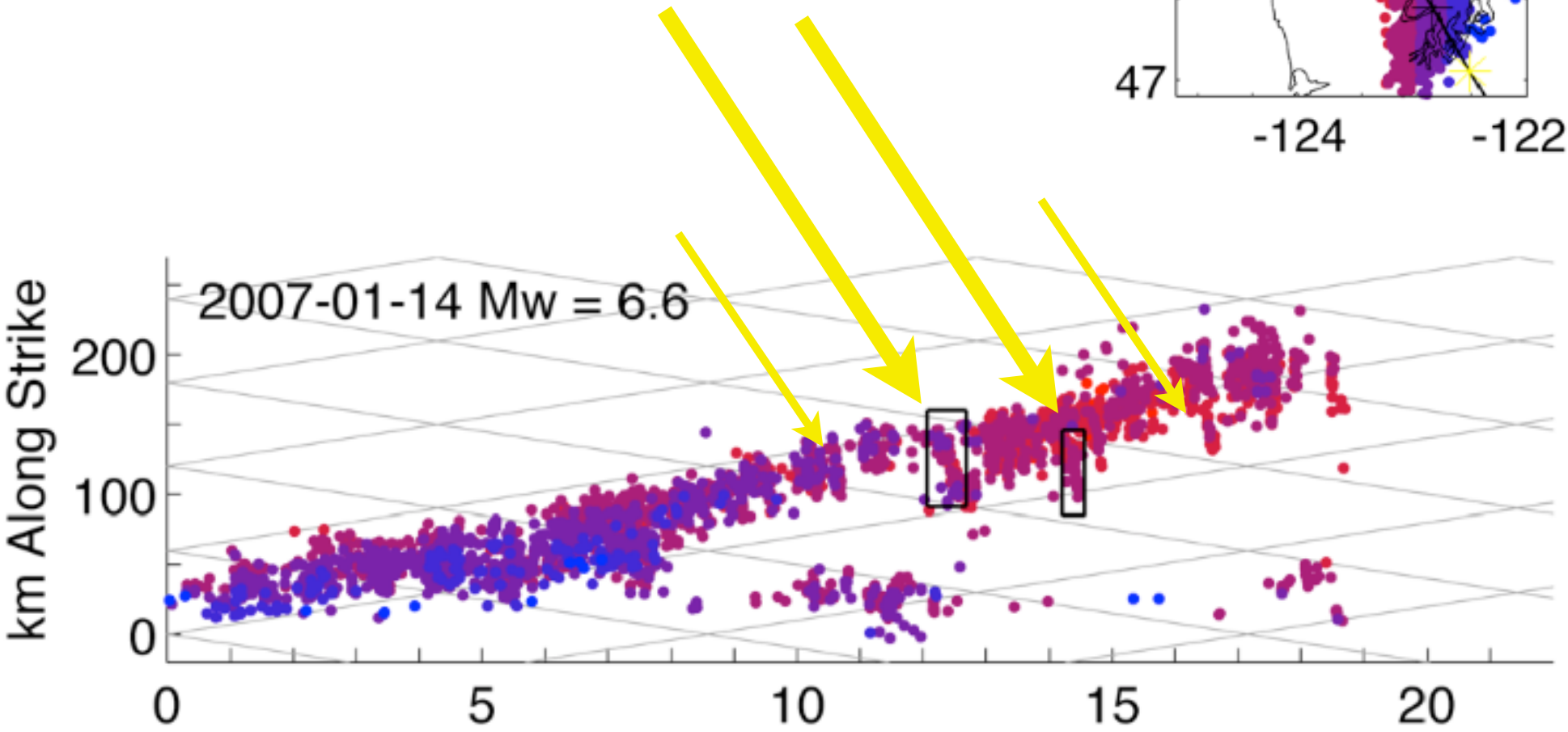




movie by: A. Ghosh

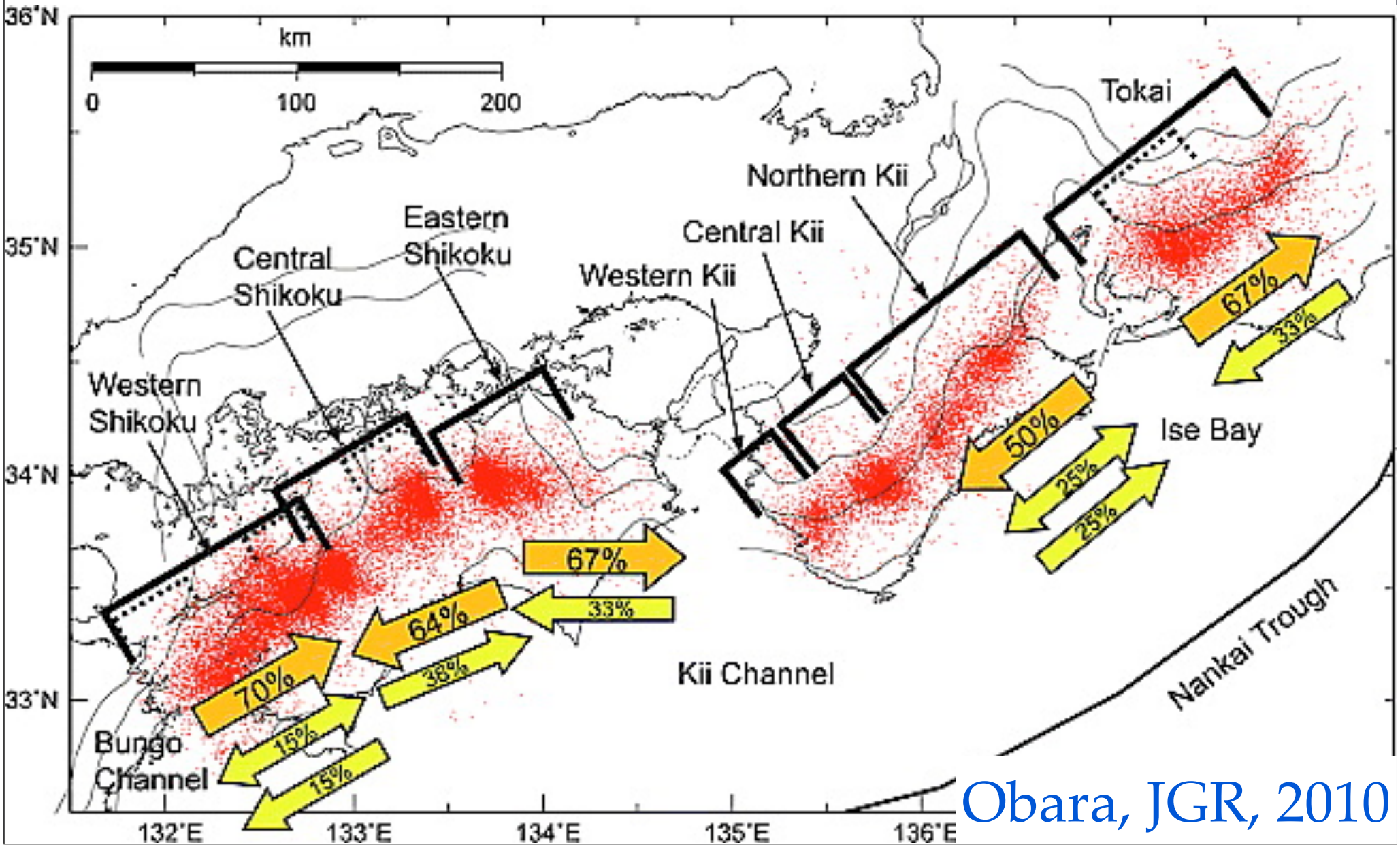
RTR's - Rapid Tremor Reversals





Houston, Delbridge, *et al.*, in review

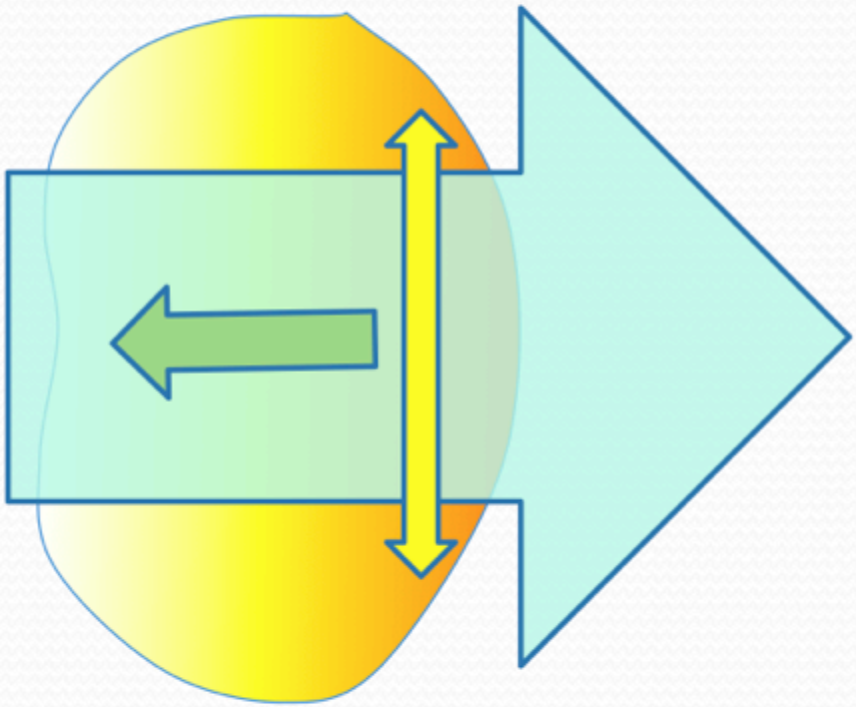
Characteristic migrations



Obara, JGR, 2010

A hierarchy of tremor migration patterns and their relation to slow slip

- Long term migration driven by slow slip front
- Rapid tremor reversals back into the slow slip pulse
- Streaks along the leading edge of the slow slip front



Tremor migration speed

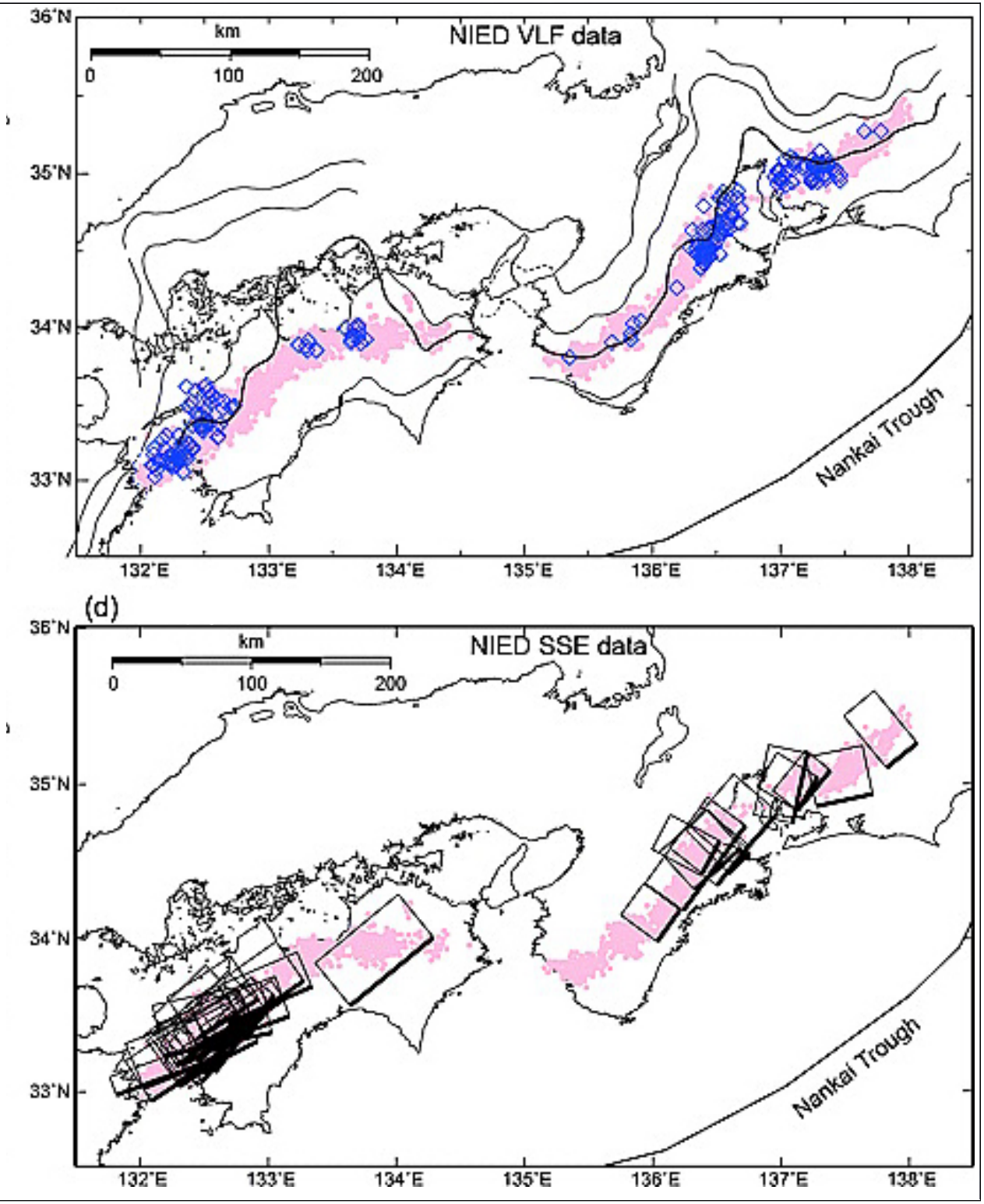
10 km/day
100 km/day
1000 km/day

Slow slip rate

100 cm/yr
1 cm/yr

→ **Tremor migration speed correlates with slow slip rate**

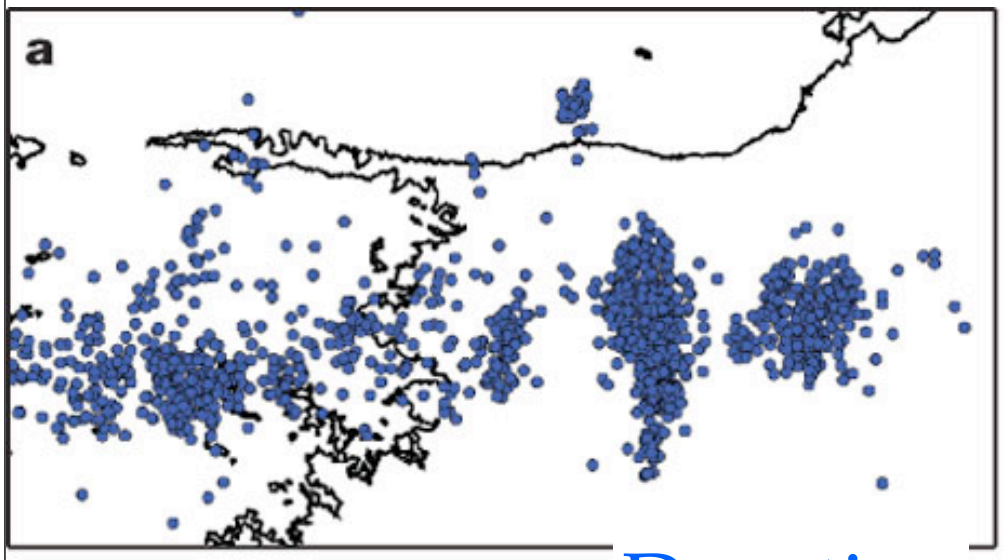
LFE vs tremor

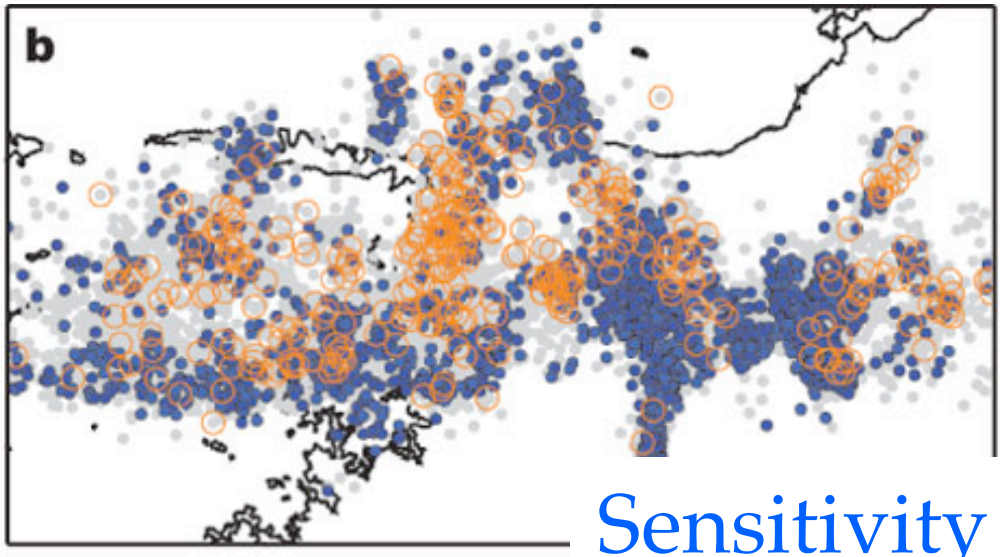


Obara, JGR, 2010

All LFEs

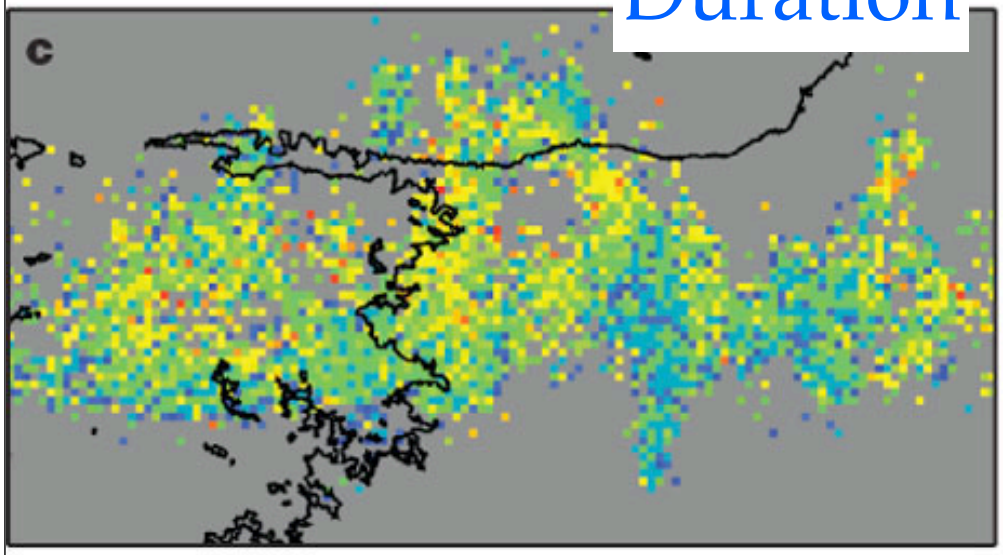
short vs long LFEs

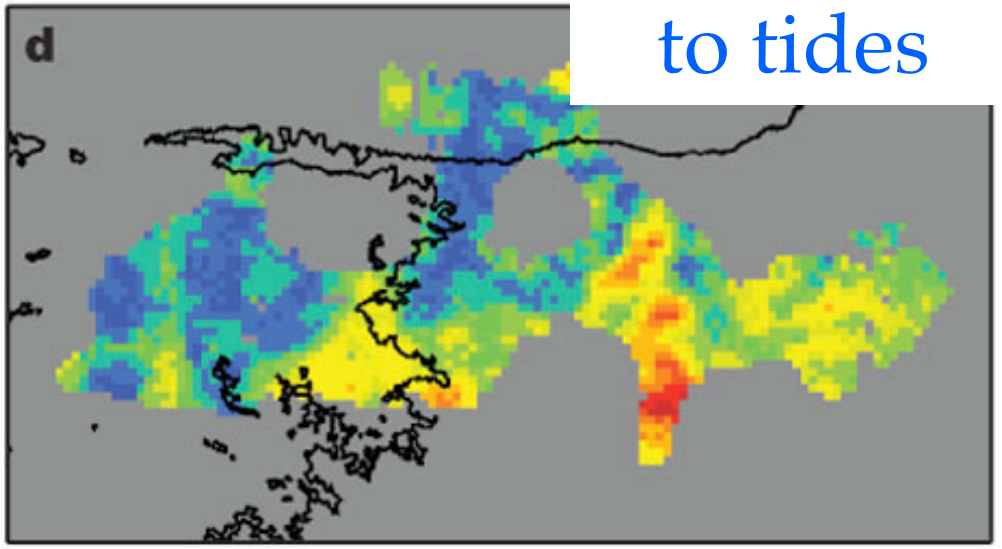


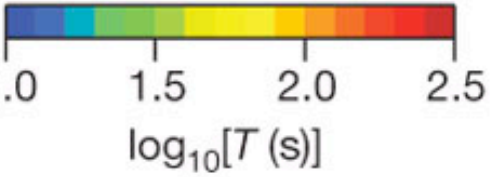


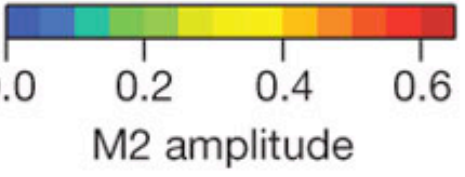
Duration

Sensitivity to tides



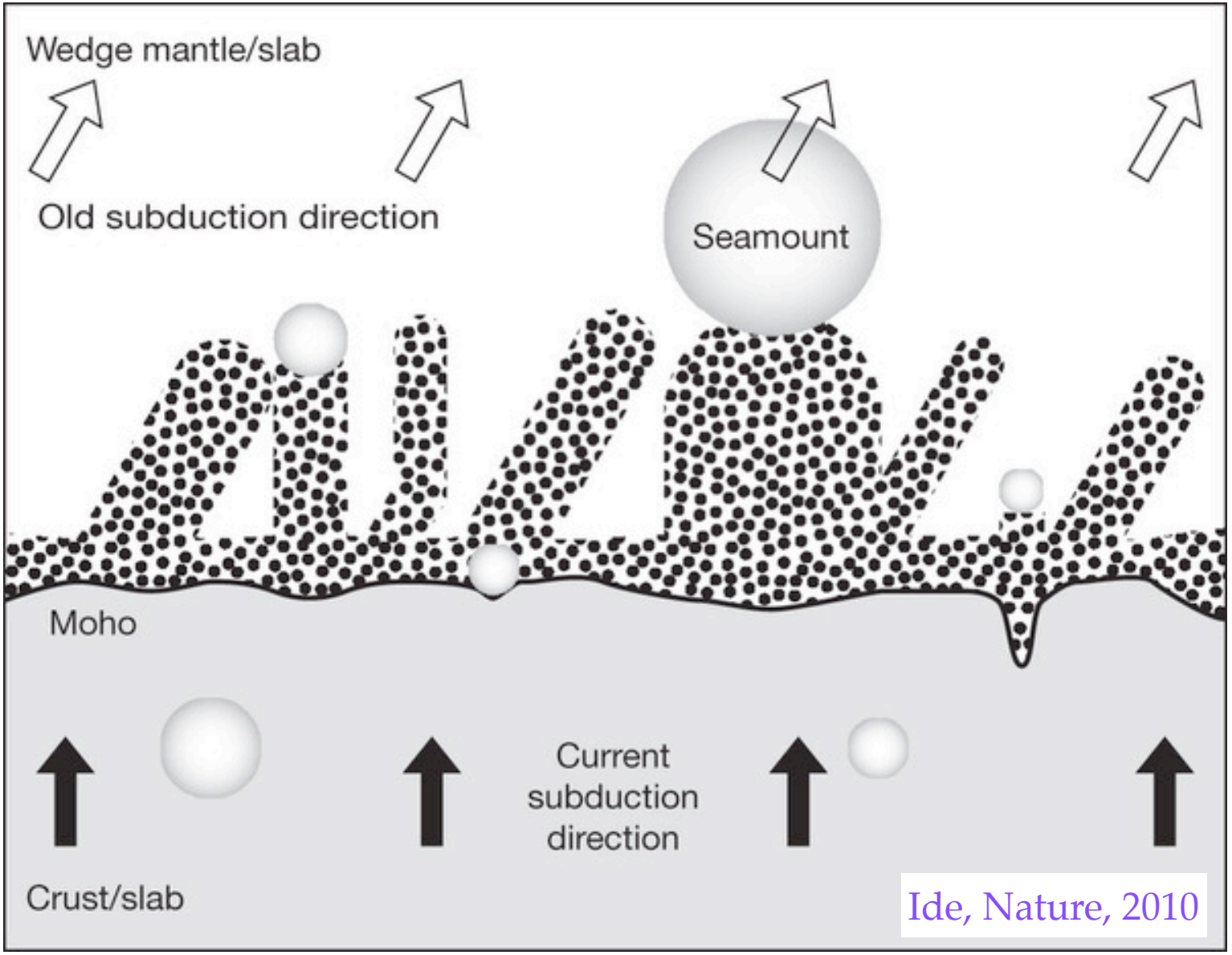




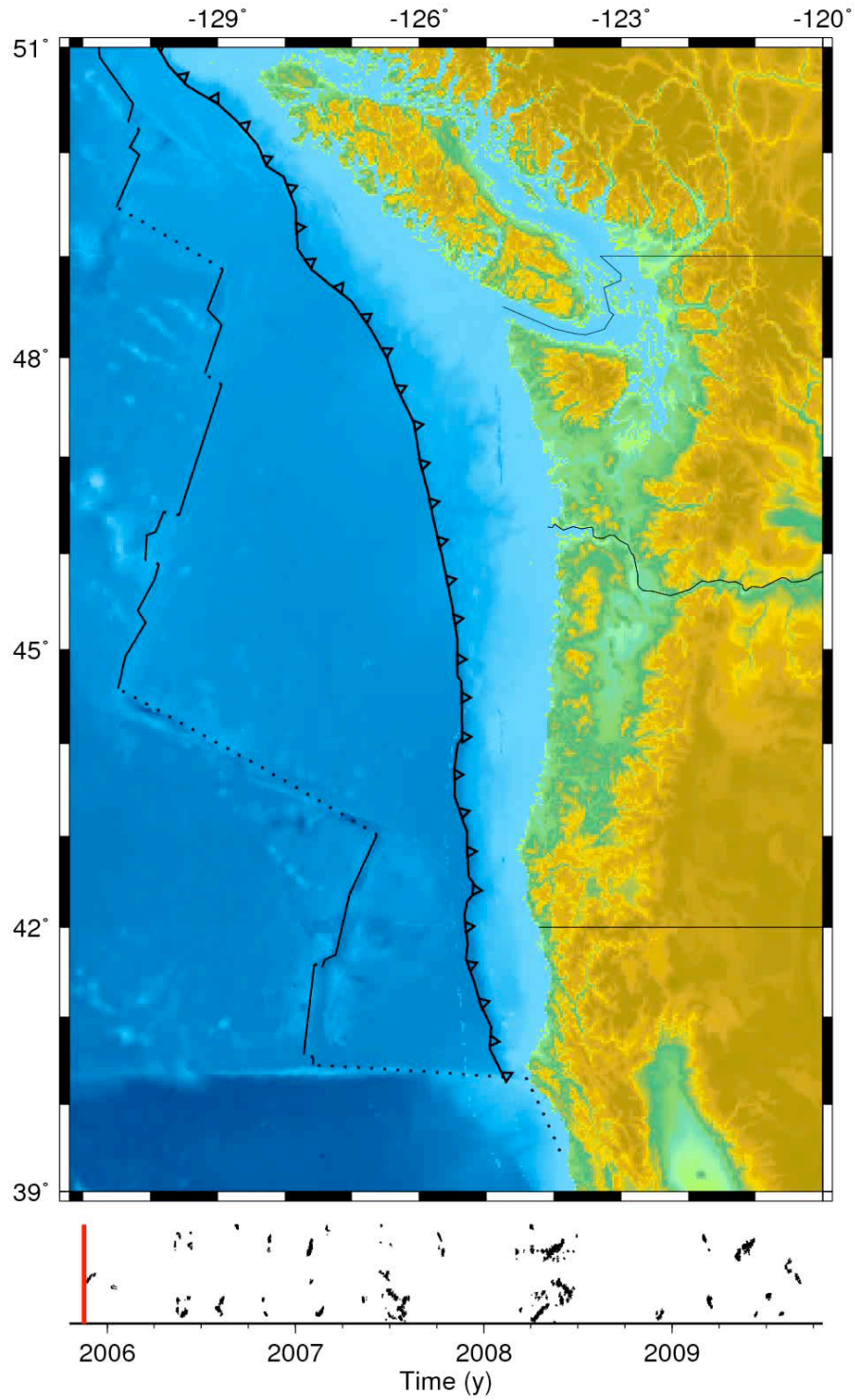


Ide, Nature, 2010

Tremor stripes vs geology



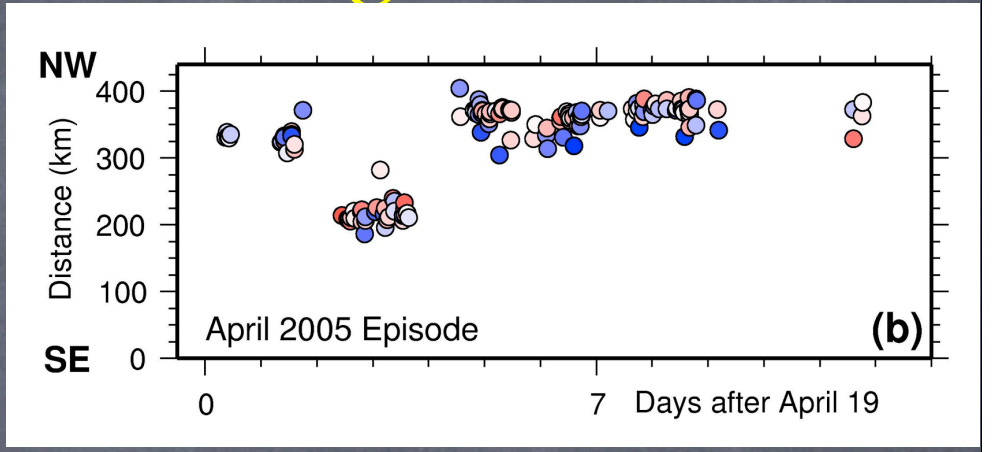
Tremor fills Cascadia



Courtesy Mike Brudzinski

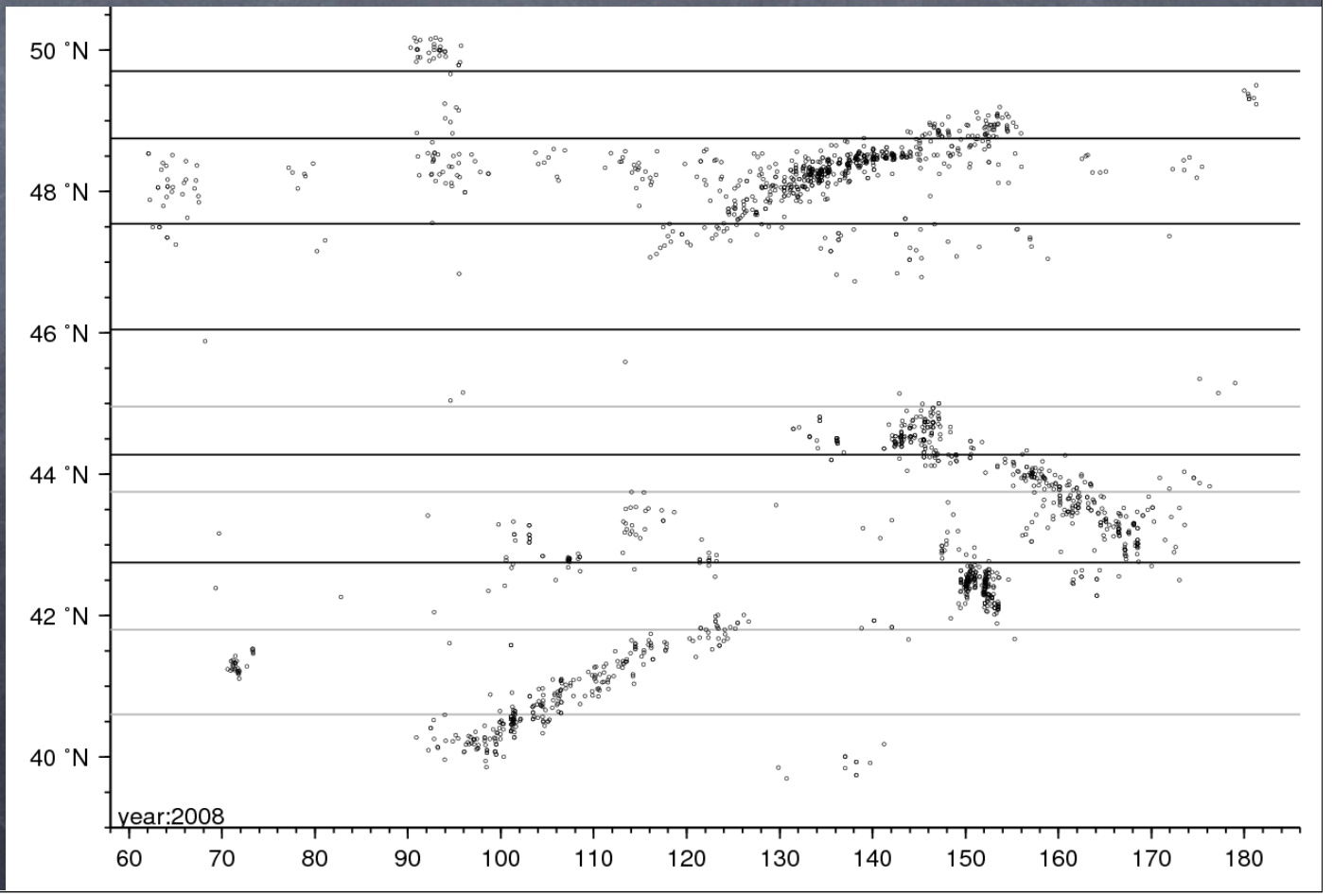
Along Strike Migration and Segmentation

Kao et al., 2007



- Steady movement, halting, jumping
- 2008 event occurred over nearly the entire margin

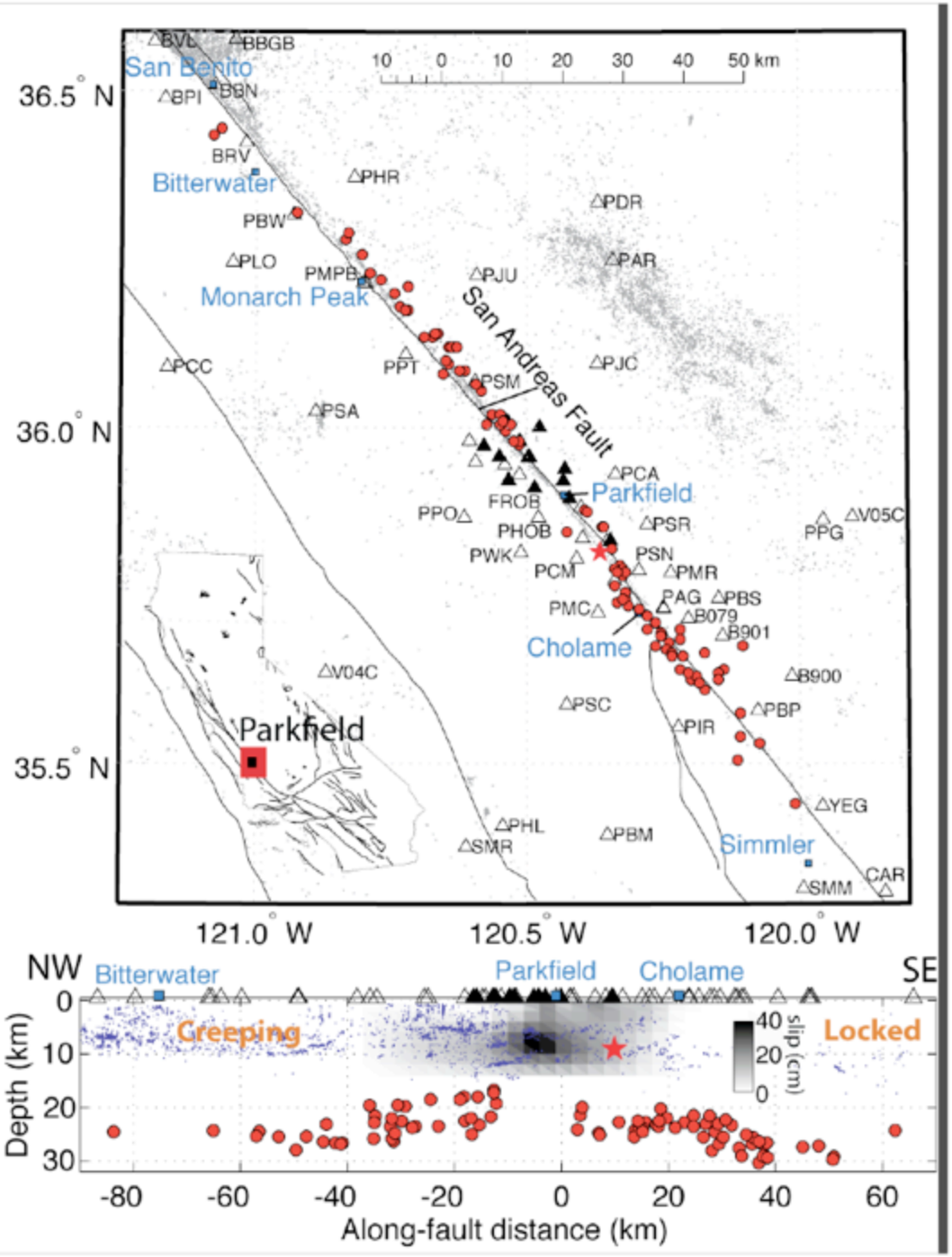
Brudzinski, pers. comm.



Parkfield Tremor Locations

- 88 stacked LFE templates
- Located by P and S arrivals on stacked waveforms, using a 3D velocity model.
- Sources extend 75 km both NE and SW of Parkfield

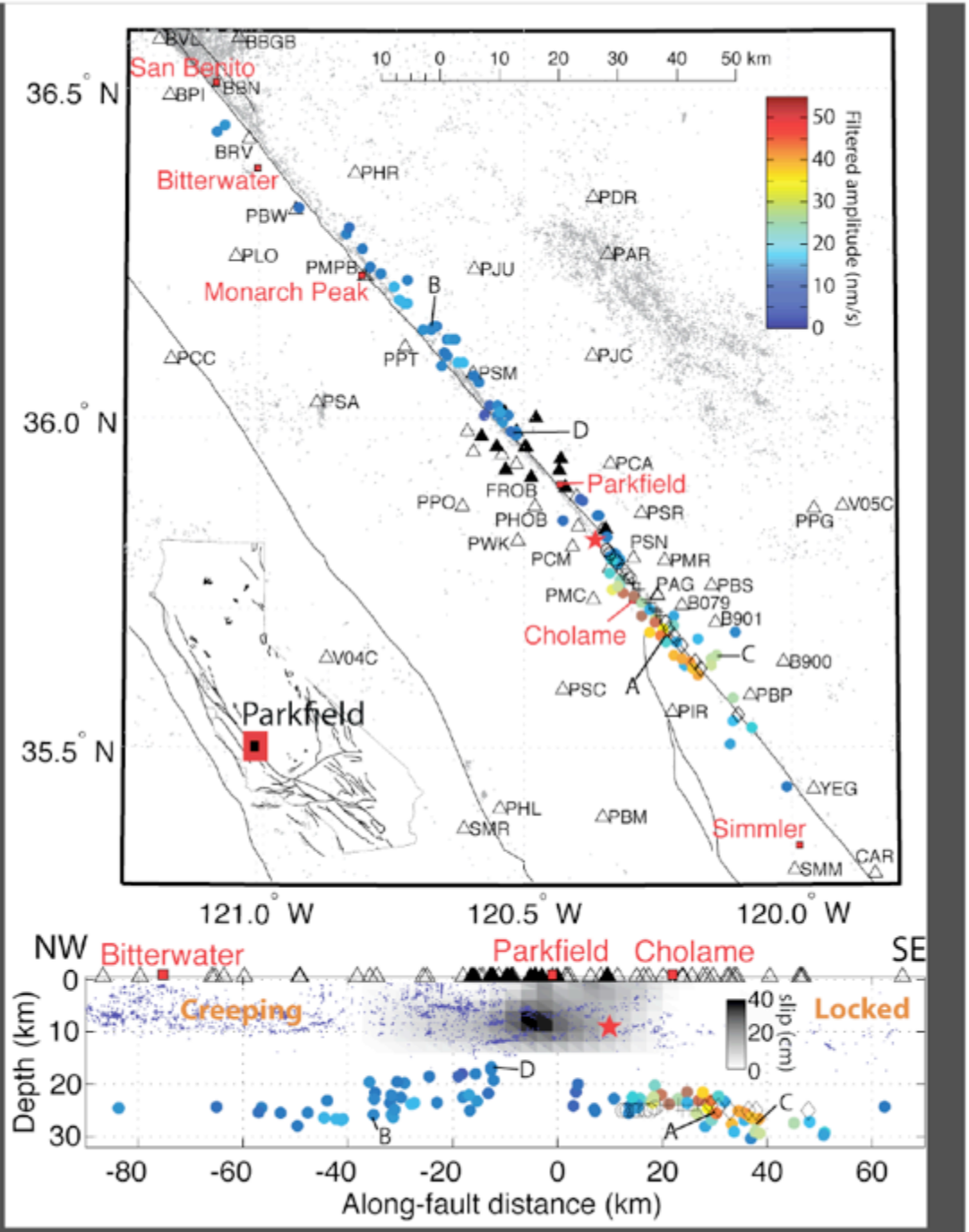
Shelly and Hardebeck, GRL, 2010



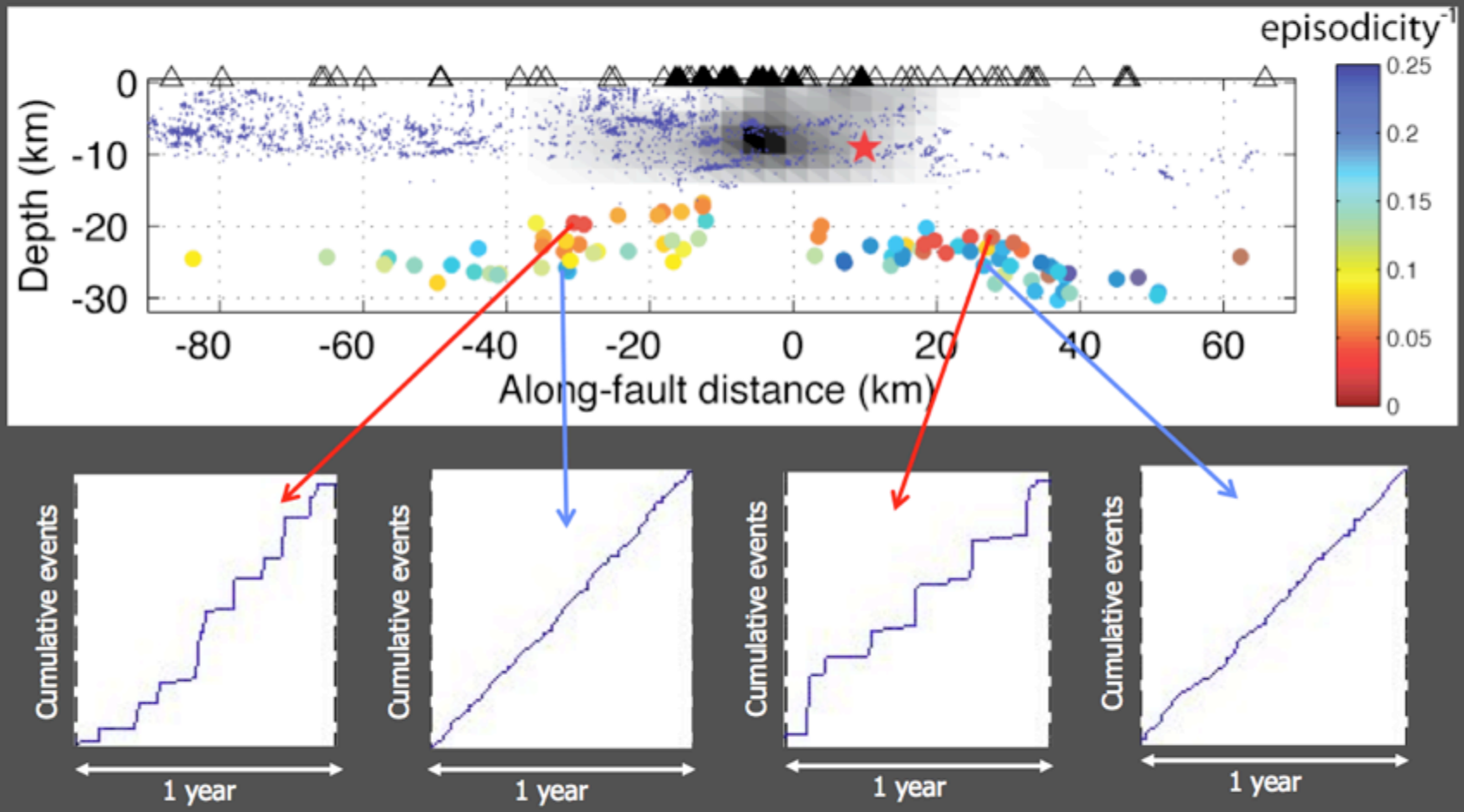
Amplitude potential

- Characterize source amplitude as peak ground velocity of 20th largest event during 2001-2010.
- Avoids bias from large amplitude outliers (EQs/ noise) and large number of small amplitude events

Shelly and Hardebeck, 2010

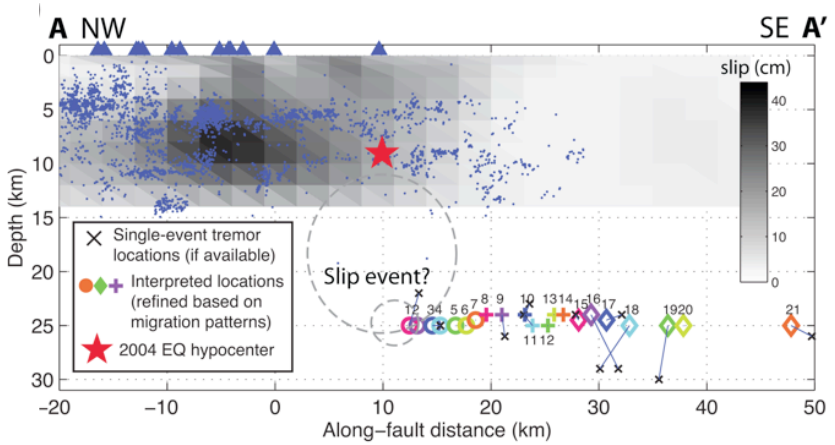


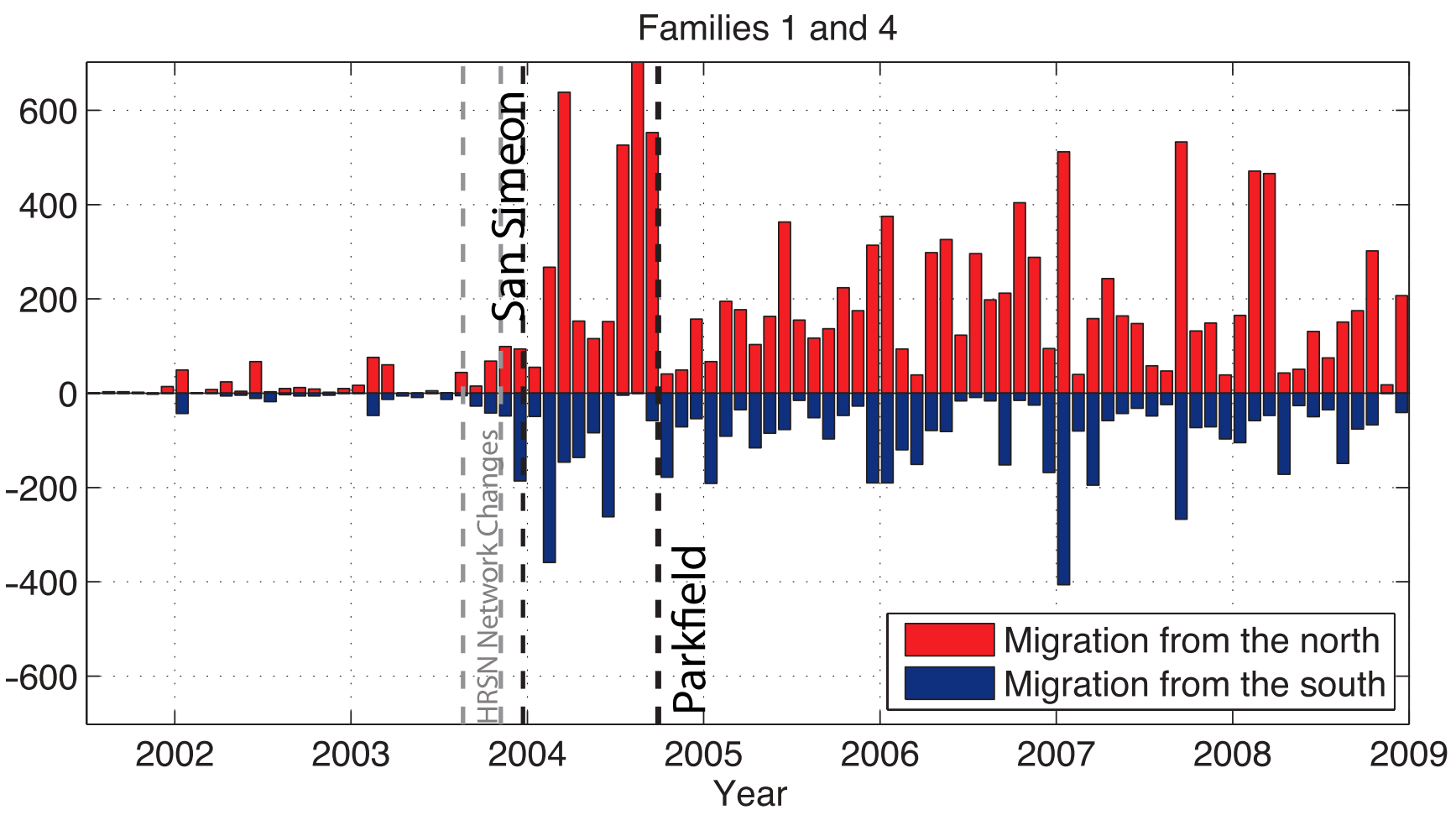
Shallower sources have larger, less frequent bursts



Shelly, in prep.

Parkfield precursors?





Shelly, GRL, 2009

Wrap-up

- Activity migration
  - Along strike ~10 km/day,
  - Reversing pulses ~100 km/day
  - Down-dip 10s of km/hr,
  - Flickering by the second,
  - Repeating patches, and
  - Perhaps jumping 100s of kms.
- Progress will come from further observations
  - ETS relation to earthquakes,
  - ETS relation to geology, and
  - ETS fine-scale spatiotemporal evolution.
- Imagination fails me here.